SCIENTIFIC AGRICULTURE

LA REVUE AGRONOMIQUE CANADIENNE

VOLUME XVIII

September 1937 - August 1938

EDITED BY THE
CANADIAN SOCIETY OF TECHNICAL AGRICULTURISTS AT
OTTAWA, CANADA

Published monthly by the authority of the
Chairman of the National Committee on Agricultural Services

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ERRATUM

In the December 1937 issue, Volume XVIII, No. 4, the illustration over the caption for Figure 19, page 192, belongs to Figure 20, page 195, and the illustration over the caption for Figure 20 belongs to the caption for Figure 19.

SCIENTIFIC AGRICULTURE

Vol. XVIII SEPTEMBER, 1937 No. 1

THE MINERAL CONTENT OF TIMOTHY HAY AND OAT STRAW AS FED IN EASTERN CANADA[1]

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At a meeting of the executive of the Eastern Section of the Canadian Society of Animal Production in the fall of 1936, a discussion centred around the mineral content of home-grown live stock feeds, with particular reference to observed deficiencies in these minerals in certain localities. It was felt that the problem was deserving of further study and Dr. Archibald suggested that the Dominion Experimental Farms would undertake investigations in this connection. The purpose of this paper is to report the progress which has been made in preliminary investigations to date.

The ground work for the study was laid at the Central Experimental Farm, Ottawa, at a meeting of several of the Divisions concerned, when it was decided to collect samples of oat straw and timothy hay from farms at a number of points throughout Eastern Canada and have them analyzed to determine their mineral content. It was felt that if analyses of these two widely grown crops showed any marked deficiencies in mineral content, it would be a fairly reliable indication of any general deficiency in calcium and phosphorus which might exist in soils, and also in other crops in a particular district, and that this might be related to mineral deficiencies in the live stock of the district.

The Dominion Experimental Farms and Illustration Stations located as they are throughout Eastern Canada, in representative agricultural districts, provided a convenient means of obtaining samples for analysis. Samples of oat straw were received from 111 Illustration Stations and eight Experimental Farms and of timothy hay from 114 Illustration Stations and nine Experimental Farms.

INFORMATION FROM QUESTIONNAIRES

The chemical data obtained from the analyses of these samples was supplemented by information from questionnaires in regard to feeding practices, evidence of mineral deficiency, type of soil, and fertilizer treatments. In reply to the question: "Have you noticed any evidence of mineral deficiency in the forage crops fed to your cattle, as indicated by their chewing bones, wood, leather, iron or earth, particularly in the spring

[1] An address delivered before the Eighth Annual General Meeting of the Canadian Society of Animal Production (Eastern Section) at the Central Experimental Farm, Ottawa, Ont., on June 16, 1937.

[2] Respectively, Chief Assistant, Division of Field Husbandry, and Assistant Chemist, Division of Chemistry.

and early summer months", 69 operators of Illustration Stations reported that such evidence existed while 38 had noticed no deficiency. This alone is evidence of the prevalence of mineral deficiencies.

In regard to feeding practices, in 100 replies the average amount of hay fed was 19.9 pounds per day. Eighty-six co-operators fed roots at an average rate of 25.4 pounds per day. Comparatively few fed silage, 12 only reporting, and the average amount fed was 23.2 pounds per day. Twenty-six fed oat straw to their cattle at an average rate of 11.2 pounds per day. Eighty reported that they were feeding grain or a meal mixture and 35 that no meal was being fed. The average rate of feeding meal was 4.9 pounds per day. In reply to the question, "Are you including or have you ever included in your grain mixture any mineral supplements such as bone meal, fish meal or lime?" 27 replied in the affirmative and 13 had not supplied such supplements. Where mineral supplements had been fed 22 reported beneficial results, while four could see no improvement.

In an attempt to correlate soil type with mineral deficiency it was found that 60% of those whose farms were located on clay and clay loam soils had experienced some indication of mineral deficiency. On the lighter soils and on muck soils the percentage was higher, there being 79% on sandy loam soils, 88% on gravelly loam and 80% on the highly organic muck soils which are relatively low in minerals.

On Experimental Farms a slightly different condition exists than that which prevails on the Illustration Stations. Nine Experimental Farms sent in reports to questionnaires and at all of the Farms with the exception of Charlottetown, P.E.I., mineral supplements were fed to the live stock. The result was that only one farm reported any evidence of mineral deficiency and this was at Lennoxville in the Eastern Townships of Quebec. Hay, roots or silage, and meal were fed in fairly liberal amounts at all Experimental Farms.

CHEMICAL ANALYSES OF OAT STRAW AND TIMOTHY HAY

All of the samples of oat straw and timothy hay from Experimental Farms and Illustration Stations were analysed to determine the percentage of calcium and phosphorus which they contained. Table 1 lists the number of samples from each of the geographical districts.

Naturally considerable variation is expected in samples secured more or less at random from the mows of farms in widely separated localities. Many factors unite to make the correlation of results very difficult. Crops are harvested under variable climatic conditions some of which favour the satisfactory curing of the crop while others produce varying degrees of weathering. The crops, particularly the timothy, are cut at different stages of maturity which effects the chemical composition considerably. The chemical nature of the leaf of the plant is different from that of the stemmy portions and where difficulties in harvesting present themselves, very often a large number of leaves are lost. In the case of timothy hay, it is very difficult to obtain it free from clover, as a mixture of clover and timothy seed is usually sown. The presence of clover increases the mineral content, particularly the calcium, quite markedly.

With a view to eliminating as many of these factors as possible, a botanical examination was made of the samples by Mr. W. G. Dore of

TABLE 1.—NUMBER OF SAMPLES OF OAT STRAW AND TIMOTHY HAY RECEIVED FROM VARIOUS DISTRICTS IN EASTERN CANADA

Province or District	Station	Oat straw No. of samples	Timothy hay No. of samples
Prince Edward Island	Illustration Station Experimental Station	14 1	14 1
Nova Scotia	Illustration Station Experimental Station	13 1	13 2
New Brunswick	Illustration Station	19	18
Eastern Quebec	Illustration Station Experimental Station	18 2	18 1
Lake St. John	Illustration Station	3	3
Central Quebec	Illustration Station Experimental Station	11 2	11 2
Eastern Ontario and Western Quebec	Illustration Station Experimental Station	15 1	15 1
Northern Ontario and Northern Quebec	Illustration Station Experimental Station	18 1	22 4
	Total	119	125

the Botanical Division, Central Experimental Farm, Ottawa. In this examination it was possible to determine the percentage of legumes, weeds, and other foreign matter in the samples. Consideration was given to the estimated stage of maturity at which the samples were harvested. Observations were made in regard to weathering which was characterized by the colour of the sample and its general appearance.

From this examination it was determined that 18 of the samples of straw were of poor colour and 21 samples only fair, which indicated a considerable amount of weathering. In the samples of hay 22 were poor in colour and 34 fair. Forty-six samples of hay contained legumes in amounts varying from 5 to 85%.

With these and other observations it was possible to select data which more truly represented comparable samples of the feeds in question. The analyses for oat straw have been affected by weathering and in cases where this was indicated by a high calcium content, the data have not been used. There was not much adulteration of the straw samples by other herbage, but the hay samples often contained a considerable proportion of other grasses, legumes, and weeds. The presence of the legumes would have the greatest effect in altering the composition and where this effect has been appreciable, the data have not been included in the comparison of timothy samples. As with the oat straw, where there were evidences of severe weathering the data were discarded.

The chemical data presented herewith are calculated on a dry matter basis. The percentage of calcium and phosphorus on this basis is only

slightly higher than that contained in the forages as they are normally fed to the live stock; since the moisture content is probably not over 10%, the percentage of the two minerals is low. A summary of the data is presented in Tables 2 and 3 and is an attempt to give maximum, minimum and average figures for normal and normally harvested forages as representative of the districts where they were grown.

TABLE 2.—PERCENTAGE OF CALCIUM AND PHOSPHORUS IN SAMPLES OF OAT STRAW FROM VARIOUS DISTRICTS IN EASTERN CANADA

Locality	No. of samples	Calcium (water-free basis)			Phosphorus (water-free basis)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
		p.c.	p.c.	p.c.	p.c.	p.c.	0.c.
Prince Edward Island							
Illustration Stations	14	0.37	0.17	0.28	0.16	0.03	0.09
Experimental Station (Charlottetown)	1	0.48	0.48	0.48	0.16	0.16	0.16
Nova Scotia							
Illustration Stations	12	0.30	0.20	0.26	0.12	0.04	0.07
Experimental Station (Kentville)	1	0.19	0.19	0.19	0.07	0.07	0.07
New Brunswick							
Illustration Stations	18	0.42	0.17	0.30	0.15	0.03	0.07
Eastern Quebec							
Illustration Stations	16	0.40	0.19	0.31	0.13	0.02	0.07
Experimental Stations (Cap Rouge and Ste. Anne)	2	0.41	0.36	0.39	0.16	0.11	0.14
Lake St. John							
Illustration Stations	1	0.28	0.28	0.28	0.06	0.06	0.06
Central Quebec							
Illustration Stations	11	0.55	0.21	0.35	0.19	0.04	0.10
Experimental Stations (Lennoxville and Farnham)	2	0.39	0.37	0.38	0.17	0.09	0.13
Eastern Ontario and Western Quebec							
Illustration Stations	14	0.53	0.24	0.36	0.13	0.03	0.07
Experimental Stations (L'Assomption)	1	0.26	0.26	0.26	0.07	0.07	0.07
*Northern Ontario and Quebec**							
Illustration Stations	16	0.53	0.18	0.34	0.14	0.02	0.09
Experimental Stations (Kapuskasing)	1	0.29	0.29	0.29	0.07	0.07	0.07

* Including Northwestern Ontario.

DISCUSSION OF RESULTS OF CHEMICAL ANALYSES OF OAT STRAW

Illustration Stations

Calcium

The average percentage of calcium in the samples of oat straw from Illustration Stations in Eastern Canada as presented in Table 2, ranged from 0.26 in Nova Scotia to 0.36 in Eastern Ontario and Western Quebec.

In the standard work of F. B. Morrison published in *Feeds and Feeding* the average calcium content of oat straw is 0.36%. In Nova Scotia only two out of 12 samples were over 0.30%. In Prince Edward Island it was very little higher, the average content being 0.28%. Lake St. John District in Quebec (one sample only) was the same as Prince Edward Island. Farther west a slightly higher percentage was noticed, Eastern Quebec showing an average of 0.31%, while in Central Quebec the average was 0.35%, Eastern Ontario and Western Quebec 0.36% and Northern Ontario and Northern Quebec 0.34%.

In Central Quebec 7 out of 11 samples analysed contained 0.36% or more and were as high as the average of Morrison. In Eastern Ontario and Western Quebec 11 out of 14 samples reached the standard or exceeded it. These districts might, therefore, be considered as producing oat straw of average quality in respect to lime. The samples from other districts of Eastern Canada are below the standard on the average although with the exception of Nova Scotia, certain of the samples from all districts showed a calcium content above 0.36%.

Experimental Farms and Stations

As was the case with the Illustration Stations in Nova Scotia the calcium content of the oat straw from the Experimental Station, Kentville, Nova Scotia, was very low, being 0.19%. Contrary to the figures from Illustration Stations, on the other hand, were those from Charlottetown, P.E.I., with an unusually high calcium content of 0.48%, while the figure for L'Assomption in Western Quebec and Kapuskasing in Northern Ontario were low with 0.26 and 0.29% respectively. The samples from the Experimental Stations in Eastern and Central Quebec were of good quality in respect to calcium, Cap Rouge and Ste. Anne in Eastern Quebec analyzing an average of 0.39% and Lennoxville and Farnham in Central Quebec 0.38%.

Phosphorus in Oat Straw

Illustration Stations

The phosphorus content of the samples of oat straw have been low on the basis of average figures. Morrison shows the average figure for phosphorus in oat straw is 0.13%. This figure is reached and even exceeded in the best samples of each province but throughout the series many of the forages had a phosphorus content of less than 0.10% and a considerable number under 0.06%. The average figure is about 0.07% which is considerably lower than normal.

Undoubtedly this is a lower figure than that for the standing crop since other work has shown that the phosphorus compounds are lost in weathering much more readily than the calcium. The results of this investigation corroborate this statement. It cannot be stated, however, that in all cases where there is a low phosphorus content that the appearance of the herbage suggests that the small percentage of phosphorus can be attributed to weathering only. What other factors influence this ash constituent throughout the various districts it is impossible to say without further investigation, but in all localities the phosphorus content is low and in many samples seriously so.

Experimental Farms and Stations

On some of the Experimental Farms and Stations the phosphorus content of the straw was relatively high. At Charlottetown, Ste. Anne, and Farnham the samples were above average in this regard. At Cap Rouge the phosphorus was 0.11% or slightly below average, while at Kentville, Lennoxville, L'Assomption and Kapuskasing, as on the Illustration Stations, it was very low ranging only from 0.07 to 0.09%.

RESULTS OF CHEMICAL ANALYSES OF TIMOTHY HAY

The percentage of calcium and phosphorus in the samples of timothy hay from various districts in Eastern Canada are presented in Table 3.

TABLE 3.—PERCENTAGE OF CALCIUM AND PHOSPHORUS IN SAMPLES OF TIMOTHY HAY FROM VARIOUS DISTRICTS IN EASTERN CANADA

Locality	No. of samples	Calcium (water-free basis)			Phosphorus (water-free basis)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
Prince Edward Island							
Illustration Stations	9	0.48	0.20	0.38	0.15	0.07	0.11
Experimental Station (Charlottetown)	1	0.37	0.39	0.39	0.13	0.13	0.13
Nova Scotia							
Illustration Stations	10	0.51	0.28	0.40	0.19	0.16	0.12
Experimental Station (Kentville)	1	0.56	0.56	0.56	0.09	0.09	0.09
New Brunswick							
Illustration Stations	17	0.45	0.18	0.31	0.15	0.09	0.12
Eastern Quebec							
Illustration Stations	8	0.52	0.24	0.39	0.13	0.10	0.11
Experimental Station (Ste. Anne)	1	0.31	0.31	0.31	0.14	0.14	0.14
Lake St. John							
Illustration Stations	1	0.29	0.29	0.29	0.09	0.09	0.09
Central Quebec							
Illustration Stations	9	0.53	0.26	0.41	0.18	0.01	0.11
Experimental Stations (Lennoxville and Farnham)	2	0.49	0.35	0.42	0.16	0.13	0.15
Eastern Ontario and Western Quebec							
Illustration Stations	8	0.44	0.30	0.39	0.16	0.11	0.13
Experimental Stations (L'Assomption)	1	0.40	0.40	0.40	0.12	0.12	0.12
Northern Ontario and Quebec							
Illustration Stations	15	0.48	0.23	0.41	0.17	0.08	0.12
Experimental Station (Kapuskasing) (Unfertilized)	2	0.53	0.45	0.49	0.12	0.11	0.12

* Including Northwestern Ontario.

DISCUSSION OF RESULTS OF CHEMICAL ANALYSES OF TIMOTHY HAY

Calcium

Illustration Stations

The average calcium content of timothy hay from Illustration Stations was fairly satisfactory. The figures for New Brunswick were lower than the other provinces and might be considered too low. Thirteen out of 17 samples were below 0.40% and the average for the province was 0.31%. Stage of maturity may account for this lower calcium content. Morrison shows considerable variation of this mineral at different stages of maturity; harvested after early bloom the average percentage of calcium is 0.41 while the crop harvested in full bloom averages only 0.27%. As timothy hay is usually harvested in this later stage the calcium content in general is well up to the average. There appears to be no evidence of calcium deficiency in the timothy hay samples from either Illustration Stations or Experimental Farms or Stations.

Phosphorus

Illustration Stations

The average percentage of phosphorus in the samples of timothy hay from Illustration Stations was 0.12. This is slightly lower than the 0.16% average of Morrison. A considerable number of samples had a normal phosphorus content and the average is not far below normal. There were, however, a large number of samples with less than half the average amount of this element. This low content may have been due to weathering and loss of leaf and it would seem advisable in future work to attempt to obtain samples which are free from the influence of these factors. Very little variations can be noted in the phosphorus content of the hay from various districts.

Experimental Farms and Stations

In general, the phosphoric acid content of the hays sent in by Experimental Farms is relatively high with the exception of Kentville. The low phosphorus and high calcium content of the Kentville samples suggest the probability of loss through leaching.

THE INFLUENCE OF LEGUMES ON THE MINERAL CONTENT OF HAY

As mentioned previously there were throughout the series scattered samples of timothy hay with an admixture of legumes sufficient to influence the composition. The calcium and phosphorus content of these samples have been determined and are presented in Table 4. For purposes of comparison the average analyses of pure timothy hay are also included in the table.

The figures in Table 4 show the value of legumes. Although the number of samples of pure timothy was not the same as those which included legumes the averages show definitely the higher mineral content where the legumes were present. The average calcium content was approximately 0.38% for pure samples, whereas the figures for hay with legumes ranged from 0.59 to 1.82%. The influence of legumes is not so marked on the phosphorus content but in each case the average is somewhat higher in this respect also.

TABLE 4.—COMPOSITION OF TIMOTHY HAY AS INFLUENCED BY AN ADMIXTURE OF LEGUMES

Locality	Calcium		Phosphorus	
	Timothy	Timothy and legumes	Timothy	Timothy and legumes
	p.c.	p.c.	p.c.	p.c.
Illustration Stations				
Prince Edward Island	0.38	0.90	0.11	0.21
New Brunswick	0.31	0.82	0.12	0.12
Eastern Quebec	0.39	0.83	0.11	0.14
Lake St. John	0.29	0.68	0.09	0.16
Central Quebec	0.41	0.71	0.11	0.14
Eastern Ontario and Western Quebec	0.39	0.59	0.13	0.13
Northern Ontario and Northern Quebec	0.41	0.87	0.12	0.12
Experimental Stations				
Cap Rouge, Quebec		0.63		0.19
Kapuskasing, Ont.	0.49	1.08	0.12	0.13

In this connection an interesting point arises regarding the samples from Kapuskasing, Ontario. Two samples were furnished from fertilized hay and two from unfertilized. The average percentage of calcium in the hay from the unfertilized plots was 0.46 as compared with 1.08 from the fertilized plots. The phosphorus averaged 0.12% in both the unfertilized and fertilized samples. It is possible that the fertilizing increased the calcium due to the indirect effect of encouraging the growth of legumes as the unfertilized plots contained approximately 87% timothy and 13% legume while on the fertilized area the legumes predominated with approximately 70% legumes and 30% timothy.

Due to so many variable factors little or no correlation could be found between the mineral content of the forages and the observed deficiencies in the live stock, the type of soil, and other points covered in the questionnaire. The low mineral content appeared to be equally as prevalent on heavy soils as on light soils, and low mineral content as determined by chemical analysis was not always associated with observed mineral deficiencies in the animals.

SUMMARY

1. These investigations include data on the mineral content of 119 samples of oat straw and 125 samples of timothy hay collected from Illustration Stations and Dominion Experimental Farms and Stations in Eastern Canada.

2. The chemical data are supplemented by information from questionnaires regarding feeding, evidence of mineral deficiency, soil type, etc.

3. Oat straw samples. The average calcium content of oat straw in the various districts was: Central Quebec 0.35%, Eastern Ontario and Western Quebec 0.36%, and Northern Quebec and Northern Ontario 0.34%, which is about normal for this mineral; in New Brunswick the content was 0.30% which is slightly below normal; in Prince Edward Island and Nova Scotia it was 0.28% and 0.26% respectively, which is considerably below average.

The average percentage of phosphorus was distinctly low throughout the series.

4. Timothy hay samples. The average calcium content of timothy hay was normal throughout. The lowest calcium was found in the New Brunswick samples but even here it was up to normal for timothy hay cut in full bloom.

The phosphorus content of the timothy hay is much nearer normal than in the case of straw. The average figure for the series was 0.12% while the standard as selected is 0.16%.

5. Legumes in the timothy hay increased the calcium content quite considerably and the phosphorus also to some extent.

ACKNOWLEDGMENTS

The authors wish to express their indebtedness to the staff of the Divisions of Illustration Stations, Animal Husbandry, and Botany for assistance in collecting and analyzing the samples of forage.

THE PLACE OF MINERALS IN SWINE NUTRITION[1]

R. G. Knox[2]

Ontario Agricultural College, Guelph, Ont.

Your Secretary has asked me to discuss the place of minerals in swine feeding, and I must say at the outset that I have experienced a considerable amount of difficulty in finding literature which deals with this phase of swine nutrition in anything like a specific manner. Possibly this fact would warrant such a paper being included on the programme of this meeting, in order that the members of the organization will realize more forcefully the necessity for investigation relative to the mineral nutrition of swine.

In view of the fact that an extensive discussion is taking place to-day on the mineral nutrition of live stock I am assuming that ample consideration will be given to the minerals supplied by farm feeds, and that the evidences of mineral malnutrition will be outlined in a general way.

EVIDENCES OF MINERAL MALNUTRITION IN SWINE

Calcium and Phosphorus.—In any discussion of mineral malnutrition it is difficult to separate calcium and phosphorus, because bone metabolism and bone growth involve both elements to such a great extent, and because the adequacy of the intake of either element in covering the animal's requirements and in avoiding nutritive disaster depends so largely upon the intake of the other, particularly when the conditions for the assimilation of both are unfavourable in the absence of vitamin D or of ultraviolet radiation. About 99% or more of the body's store of calcium is found in the bones, while the proportion of body phosphorus so located, though quite variable depending upon the ratio of skeletal to soft tissues (and hence upon stage of growth) seems to be about 80%.

In the nutrition literature the pathological condition resulting from the nutritional disturbance of bone growth in very young animals is almost universally referred to as rickets. Biochemically this condition is characterized by subnormal levels of inorganic phosphorus or of calcium in the blood, and by low percentages of mineral matter in the bones. However, the pathological condition existing in the bone varies, being either osteroporosis or true rickets, the latter condition being clearly distinguished from the former, first, by the presence of the rachitic metaphysis, a marked widening of the epiphyseal cartilage, and, second, by its occurrence only in very young animals. A confusion of osteroporosis with rickets, merely because they have not been clearly distinguished biochemically is unfortunate from any standpoint and may account in part for the observed differences between species with reference to the relative vitamin D potency of different so-called "anti-rachitics".

Pregnant sows on low-calcium diets may become lame, have difficulty in farrowing, secrete little milk, and may raise only a small proportion of their young to weaning age.

[1] An address delivered before the Eighth Annual General Meeting of the Canadian Society of Animal Production (Eastern Section) at the Central Experimental Farm, Ottawa, Ont., on June 16, 1937.

[2] Professor of Animal Husbandry.

However, swine may grow for many months with unimpaired vigour on cereal rations with no calcium supplements, provided vitamins A and D are made available in adequate amounts, and in young pigs it is unlikely that a phosphorus deficiency will occur under practical and normal conditions of feeding. On the other hand a calcium deficiency is to be expected unless special provision is made against it.

Theiler has said: "The normal functioning of the mineral metabolism of an animal depends upon the harmonious interaction of three dietary factors: vitamin, calcium and phosphorus. The absence of any one of them might be expected to have the same result in all animals, but in practice this does not seem to be the case. Some species react more readily to one deficiency than another."

An excess of either calcium or phosphorus in rations for swine will tend to impair the utilization of the other minerals and to induce deficiency symptoms.

Iodine.—Goitre is the result of a deficient supply of iodine in the food and water and is remedied by administering iodine to the breeding stock either as iodides or as iodized salt during the gestation period, or, in extreme cases, to all stock the year round.

Iron and Copper.—Among the many factors that probably contribute to the prevailing high death rate in suckling pigs is nutritional or milk anemia. This condition results from the exclusive feeding of milk to new-born pigs for periods of three to four weeks after birth, with no access to earth or vegetation, and is traceable to a deficiency in milk of iron and copper. Nutritional anemia is prevented in practical swine husbandry by assuring a supply of iron and copper to the new-born pigs. The nutrition of the sow prior to or during lactation is entirely unrelated to the occurrence of nutritional anemia in her pigs.

Sodium and Chlorine.—The breakdown in health due to lack of salt is marked by "loss of appetite", a generally haggard appearance, lustreless eyes, a rough coat, and a very rapid decline in live weight.

There is apparently a close relationship between sodium requirements and the adrenal glands, such that large doses of sodium chloride relieve the symptoms of adrenal insufficiency.

AVAILABILITY AND UTILIZATION OF MINERALS

The utilization of minerals in the ration is modified by many factors relating to the ration or to the environment. The chemical combination in which a mineral occurs in the ration, concentrations of other minerals and inorganic radicals, the concentrations of certain of the organic nutrients, particularly the vitamins, the accessibility of sunlight to the animal, may all depress or increase the utilization of the mineral in digestion and in metabolism.

Vitamin D.—The proper assimilation of calcium and phosphorus in the young growing animal is dependent upon an adequate supply of vitamin D, either by adequate exposure of the animal to sunlight, or to some other source of ultraviolet light, or by the incorporation in the ration of food materials rich in vitamin D. The indispensability of vitamin D in the nutrition of the adult pig has not been satisfactorily established.

MINERAL REQUIREMENTS OF SWINE

The total requirements of growing swine for calcium and phosphorus (with adequate vitamin D provided), expressed as a percentage of the ration fed, have been assessed as follows:

Calcium requirement— 0.34% or less—Dunlop
0.37%—Axelsson
0.30%—Spildo

Phosphorus requirement—between 0.27 and 0.30%—Hughes & Aubel
between 0.30 and 0.35%—Garrigus & Hunt
0.53% or less—Dunlop
0.20%—Axelsson
0.38%—Spildo

Thus, taking an average of these recommendations, the requirements are not far removed from 0.30% for both calcium and phosphorus.

The utilization of feed calcium is assumed to be 70%, largely on the basis of results of the Illinois Station on the calcium and phosphorus metabolism of growing swine.

Spildo estimates the growth requirements of pigs to be 5.0 grams of dietary calcium and 5.7 grams of dietary phosphorus, based on a day's gain in body weight of 500 grams, containing 0.58% of calcium and 0.57% of phosphorus. The percentage assimilations are taken at 60 for calcium and 50 for phosphorus. The growth requirements, expressed in ration percentages, would be 0.25% of calcium and 0.28% of phosphorus. The percentages given above include a maintenance quota assessed according to the Sherman method.

The necessary percentages of calcium and of phosphorus decrease as the size of the pig increases.

Hogan has estimated that the rations of brood sows should contain not less than 0.4% of calcium for the most successful reproduction, as judged by the offspring produced and a study of the bones of the sow.

The necessary calcium level increases during pregnancy from 0.22% up to 0.43% on the dry ration, and the necessary phosphorus level from 0.19% to 0.28%. The daily depositions of calcium and phosphorus for fetal growth are about equal at the eighth week of gestation, while at the sixteenth week, more than twice as much calcium as phosphorus is deposited daily. At parturition, the products of conception for an average litter of eight pigs contain 101 grams of calcium and 60 grams of phosphorus.

No quantitative information has been found of the calcium and phosphorus requirements of lactating sows as determined by feeding tests of any description. The extra requirements will of course depend upon the amount of milk produced and its composition. On the basis of the interesting study of Hughes and Hart, it may be computed that sows produce an average of 6.8 pounds of milk daily during a lactation period of 8 to 12 weeks, the maximum production being attained between the second and the fourth weeks. The composition of the milk varies considerably throughout the lactation period; on the average it contains 0.277% of calcium, 0.165% of phosphorus, and 1.44 calories of gross energy per gram. An average day's production (3084 grams) contains

8.54 grams of calcium, 5.09 grams of phosphorus, and 3434 calories of gross energy.

The Requirements for Iron and Copper.—No quantitative information in regard to the requirements of farm animals for iron and copper is available.

Undoubtedly the need of iron and copper for hemoglobin production and regeneration determines to a large extent the total requirement for these metals. However, the fact that it is possible to increase the iron and hemoglobin content of the blood of pigs above what may be considered normal or adequate levels does not indicate that ordinary rations should receive iron supplements until some definite benefit to the animal is shown to follow this hyperhemoglobinemia.

The iron or copper requirements of the animal may be greatly increased if it is producing products rich in these metals. For example, a pregnant sow stores up a total of 580 mgms. of iron in the products of conception and in the last three weeks of pregnancy she is storing iron at the rate of 9 to 12 mgms. daily, probably equal to several times her own body requirements.

The requirements for Iodine.—Orr and Leitch, in a very thorough review of iodine in nutrition, state: "Regarding the iodine requirements of farm animals we have no definite information. Nor can we deduce the requirement of animals from a knowledge of the amount required to prevent goitre, for as yet no standard and adequate dosage has been determined." However, from the iodine content of feeds and usual consumptions they have computed about the amounts of iodine that different kinds of animals consume daily in non-goitrous areas. Their estimates for swine follow:

	Body wt., lbs.	Daily iodine consumption (micrograms)
Pigs, weaned	50	40–80
Sows	400	200

Welch recommends three grains of potassium iodide weekly for pregnant sows for three months, and a total of 1.2 grams, equivalent to 10.2 mgms. daily, although admitting that this is probably at least three times as much as needed.

Salt (NaCl) requirements. Morrison and Evvard recommend for swine 0.03 to 0.12 ounce of salt per head daily.

Water requirements of Swine Water requirements are ordinarily not considered along with mineral requirements, but no apology is needed for considering water in a paper of this sort, since water is a mineral and since the intake of minerals is one of the determinants of the requirements of water.

The amount of water needed by an animal is increased by the loss of water (a) in the pulmonary circulation, determined by the rate of ventilation, the percentage saturation of the inspired air, and the temperature of the body, (b) insensible perspiration through the skin, bearing a definite relation to the heat loss from the body for a definite environmental temperature and for definite humidities above a certain high percentage

saturation, (c) the sensible perspiration, related to the amount of muscular exercise and to atmospheric conditions, and (d) the alimentary output of water, related to the amount and character of the food consumed.

PRACTICAL CONSIDERATIONS

Nutritional Anemia may be prevented by the direct feeding of reduced iron or a commercial iron salt such as ferric sulphate or ferric chloride. A practical method is to place in the pen sods or earth to which an iron salt has been added.

Phosphorus.—Since the cereal grains themselves (with the exception of rice) contain 0.3 to 0.4 or somewhat more of phosphorus and since the usual protein supplements are much richer than this in phosphorus, it seems clear that rations for growing swine do not require supplemental quantities of this mineral.

Calcium.—The calcium deficiencies of a ration may be adequately taken care of by the supplemental feeding of ground limestone or calcium carbonate. In the instance of skimmilk or protein-rich concentrates of animal origin being fed there is not such a probability of a calcium deficiency as when protein concentrates of vegetable origin are fed.

As a source of both calcium and phosphorus feeding bone meal may be fed.

The feeding of the pregnant sow with respect to calcium and phosphorus is quite similar to that of the growing pig; as she progresses in pregnancy her mineral needs approximate in intensity more and more nearly those of the weanling pig, so that during the last week of pregnancy she requires about as large a concentration of calcium and of phosphorus in her ration as does a 50-pound pig. A lactating sow, requiring an average of 0.45% of calcium and 0.37% of phosphorus in her ration on the dry basis, also presents the same sort of a picture as the weanling pig.

Vitamins.—The provision of a dependable source of the vitamins is necessary to mineral assimilation. Sufficient literature relative to this phase of nutrition is available and it remains for the feeder to make use of opportunity.

Goitre with its accompanying complications may be prevented by the feeding of iodine along with the regular ration.

ACKNOWLEDGMENT

The greater part of this data has been collected from Bulletin No. 99 of the National Research Council, *Mineral Nutrition of Farm Animals* by H. H. Mitchell and F. J. McClure.

THE PROBABLE EFFECT OF NUTRITION ON THE BUTTERFAT TEST WITH PARTICULAR REFERENCE TO MINERALS[1]

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Much yet remains to be worked out in the explanation of the phenomenon of milk secretion. Early workers definitely state that the butterfat test of milk, while it varied within certain limits, was a hereditary factor and not appreciably influenced by feeding. Present day evidence would indicate that this early hypothesis is only partially true. It still appears to be a fact that the normal butterfat test of a cow is largely fixed by heredity and cannot be increased beyond certain more or less fixed limits. On the other hand, it has been demonstrated that improper feeding, and more particularly prolonged underfeeding of some or all nutrients, will result in a reduction in both the yield of milk and the butterfat test. When this condition is corrected the test rises to the inherited ability of the cow, but not beyond this point. It should also be appreciated that there is a difference in the behaviour of the cow and the composition of the resultant production between a starvation diet and partial deficiency ration.

Since the program at this meeting is built largely around the subject of minerals and their deficiencies, it is desirable at this point to list the most important mineral elements that might be deficient in the ration. Sodium and chlorine make up salt, and all live stock men know that salt is necessary in the ration, and that unsatisfactory results occur if it is not fed. In many parts of the Dominion the soils are low in iodine with a resultant shortage of this mineral in the crops grown on these soils. Calcium may be deficient in some sections but shortages do not occur where cows are fed large quantities of legume hay. Phosphorus shortages are found in many sections of the Dominion and in many live stock countries throughout the world. Shortages in minerals are, in cattle feeding, largely confined to sodium and chlorine (salt), iodine, calcium and phosphorus. Many other minerals are required in the ration of the dairy cow but with few exceptions definite shortages have not yet been reported or, at least, not diagnosed.

Shortages of iodine have been largely demonstrated in the new born young (goitre). Latterly, however, there has been evidence indicating that this element may have a very marked influence on both milk yield and fat test. Graham (1) found that after removing the thyroid gland a marked drop occurred in both yield and test, and by adding thyroxin, a hormone secreted by the thyroid gland, the yield of milk and fat increased significantly. While the feeding of this hormone is not yet feasible in dairy feeding practice this work does demonstrate two things at least, first, that milk and fat secretion is a very complex phenomenon and not

[1] An address delivered before the Eighth Annual General Meeting of the Canadian Society of Animal Production (Eastern Section) at the Central Experimental Farm, Ottawa, Ont., on June 16, 1937.

[2] Associate Professor of Animal Husbandry.

controlled by any single factor and, second, from a practical standpoint, marked iodine deficiencies may be one limiting factor in some dairy herds. Just here it might be well to warn against excesses in the feeding of iodine since this may result in a serious breakdown in health. (One ounce of potassium iodide in 300 pounds of common salt is the mixture recommended by many authorities.)

In some sections of the Dominion calcium deficiencies are in evidence, but where legume hays, such as alfalfa, red clover or alsike are fed as the hay portion of the ration, calcium deficiency is not likely to occur. With classes of live stock such as hogs that do not eat large quantities of roughages, calcium deficiencies are more common than with other classes of stock. Since calcium deficiencies are apparently rare in cattle feeding, and since there is little information in the literature on the effect of calcium on butterfat test, the discussion on this particular mineral will be discontinued at this point.

Phosphorus deficiencies have been reported in many parts of the world and are frequently found in cattle fed largely on home-grown rations. This condition has been reported as fairly prevalent throughout Old Ontario and is more particularly pronounced in the western sections of Old Ontario. Most animal husbandrymen are familiar with the emaciated condition of cattle that are fed insufficient quantities of phosphorus. Considerable work is under way at the present time to determine if this deficiency has an effect on the butterfat test of milk, and indications at the present time point to some rather interesting results. The addition of steamed bone meal or di-sodium phosphate to home grown rations fed to dairy cows in certain cheese factory sections where the butterfat test for entire herds was running below 3% has resulted in an increase in the butterfat test in most instances. Whether this is due directly to the increase in phosphorus in the diet, or to the better assimilation of all of the nutrients when phosphorus was added to the diet, or to improved appetite, is a problem that has not yet been solved. This point must be kept in mind, however, that the herds that were testing lower than 3% were apparently not testing up to the normal inherited ability of the cows for butterfat. It is not suggested, and there is no evidence to support the statement, that phosphorus will increase the butterfat test of a cow's milk beyond her inherited ability to produce, but on the other hand, it will apparently help in bringing cows back to their normal level.

Rations that are balanced with protein rich feeds that have as a general rule a high phosphorus content, feeds such as bran, shorts, cottonseed meal and oilcake meal, will usually supply sufficient quantities of phosphorus to keep a cow up to her normal level of fat test. Where low phosphorus hay is fed and the ration made up largely of home grown grains that have been grown on soils that have a low phosphorus content the addition of some phosphorus rich mineral feed is advised. Steamed bone meal is recommended for this purpose, and evidence would indicate that in phosphorus deficiency areas it should be fed at the rate of about two pounds of steamed bone meal to each 100 pounds of concentrates supplied. Where the cattle are not fed concentrate feeds this product may be fed *ad lib* in a box in the pasture field or mixed with the salt at the rate of approximately 50% bone meal and 50% salt.

The following table will serve to illustrate the importance of feeds as sources of calcium and phosphorus:

(2) *Feeding Stuff* (2)

	Calcium %	Phosphorus %
Concentrates:		
Barley grain	0.05	0.38
Oats	0.09	0.33
Wheat	0.03	0.43
Corn	0.01	0.28
Oilcake	0.33	0.86
Cottonseed (41% protein)	0.20	1.19
Wheat bran	0.12	1.32
Distillers' corn grains dried	0.05	0.31
Bone meal steamed	32.61	15.17
Roughages:		
Alfalfa hay	1.43	0.21
Timothy hay	0.27	0.16
Oat straw	0.36	0.13
Corn silage	0.07	0.06

There is evidence to indicate that the increased use of inorganic minerals in the form of di-calcium phosphate or di-sodium phosphate may occur in the near future. New methods in the preparation of phosphates insure a product free from injurious quantities of flourine. These products have also the advantage of being more readily available than bone products, and if the price per unit of phosphorus becomes more attractive in these feeds than in bone meal an increase in their use would be expected.

Excess quantities of calcium in a ration tend to precipitate the available phosphorus and may actually aggravate phosphorus deficiencies. The writer has seen some of the most typical cases of phosphorus deficiency on farms where large quantities of alfalfa hay were fed along with a concentrate mixture made up entirely of home grown grains. From the standpoint of supplying nutrients this type of ration is quite satisfactory but it is very high in calcium and low in phosphorus. The addition of any mineral feed that contains a large amount of calcium to a ration similar to the one mentioned above is not recommended. Phosphorus rich feeds and phosphorus rich minerals should be used.

One of the unfortunate features of many of the home-mixed and commercial-mixed mineral feeds is that they contain a large amount of calcium and when fed under conditions where the ration already has an excess of calcium may actually do more harm than good. Most of the experimental work done with minerals would indicate that the simple recommendation of the liberal feeding of well balanced rations supplemented with iodized salt and steamed bone meal will supply the protein, energy, vitamins and minerals required for a cow during the lactation period and dry or fitting period.

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REGULATION OF MINERAL FEEDS UNDER THE FEEDING STUFFS ACT[1]

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The present Feeding Stuffs Act has been in effect since 1920 without change in the guarantee requirements applicable to commercial feeds. It provides no authority to require chemical guarantees other than protein fat and fibre, and consequently could not be applied to regulate the sale of mineral mixtures and various other products which have become of commercial importance during recent years.

During the past session of Parliament a new law, termed The Feeding Stuffs Act, 1937, was passed to come into effect on October 1 of this year. Many technical authorities, including a good number of those present here, and also many representatives of consumer and trade interests were consulted and contributed most helpfully in the development of its provisions. It embraces a wide range of products, the term "feeding stuff" being defined as "any article intended for consumption by live stock and purporting to supply proteins, carbohydrates, fats, minerals, condiments or vitamins, and shall include any article prepared for the purpose of preventing or correcting nutritional disorders."

During recent years a great deal has been heard regarding the mineral nutrition of live stock. For the most part scientists have been recommending relatively simple mineral mixtures. Progressive manufacturers endeavour to keep their products in line with scientific developments and teachings, but there are always elements in the trade which seek to capitalize on any subject of popular interest. Complex proprietary mineral mixtures, offered at high prices, and supported by extensive advertising, extravagant claims and high-pressure salesmanship, have become a matter of serious concern to all interested in the welfare of the live stock industry. With no guarantees required and no uniformity in analyses claimed by different manufacturers, neither feeders nor technical authorities were in a position to appraise the value or suitability, either relative or absolute, of such products; hence the need and pressing demand for some legislative control as a protection to feeders and legitimate commercial enterprise.

Under the new feed law, straight mineral mixtures, as well as supplemental feeds purported to supply both proteins and minerals in excess of the amounts required in complete or balanced meal mixtures, are subject to registration, and packages must be labelled to show:—

(a) The name and address of the registered owner;
(b) The brand and name;
(c) The registration number;
(d) The net weight of contents;
(e) The specific name of each ingredient;
(f) The guaranteed analysis setting forth the actual amounts (within permitted tolerances) of such of the following as are intentionally or purportedly present: Calcium (Ca), Phosphorus (P), Iodine (I), Iron (Fe) and Salt (NaCl).

[1] An address delivered before the Eighth Annual General Meeting of the Canadian Society of Animal Production (Eastern Section) at the Central Experimental Farm, Ottawa, Ont., on June 16, 1937.
[2] Chief, Feed Division.

While other mineral elements are required by animals, they are usually present in adequate amounts in ordinary feed; hence, in the opinion of authorities consulted, there was not need to require guarantees of chemical constituents additional to those cited.

It will be noted that only those mineral constituents which are intentionally or purportedly present need be guaranteed; in other words, where one of the listed minerals is present only incidentally as a constituent of some other ingredient, it need not be declared unless special claims for it are being made. Attention is also directed to the fact that the various minerals must be guaranteed in actual rather than minimum or maximum amounts, and, with the exception of salt, as elements rather than compounds. The primary purpose in this is to facilitate calculation of calcium phosphorus ratios, such ratios being regarded as important. Mineral constituents of feeding stuffs, as reported in the most recent edition of "Feeds and Feeding" by Morrison, are given on this basis.

Obviously, where guarantees must be given in actual amounts, some tolerances must be recognized to take care of normal variations in the composition of ingredients and also the difficulties in mixing to secure absolute uniformity. The Act provides authority to establish such tolerances by regulation. Unfortunately we have not the benefit of experience to guide us in this matter, but, after consultation with a number of feeding authorities and chemists, tentatively suggest the following:—

(a) A deficiency or excess of one-tenth of the respective amounts of calcium (Ca), phosphorus (P) and salt (NaCl) guaranteed with a maximum deficiency or excess of 3% of the bulk;

(b) A deficienty of one-tenth of the respective amounts of iodine (I) and iron (Fe) guaranteed.

With mixed supplements as well as straight mineral mixtures subject to guarantees, different commercial preparations will vary widely in the contained amounts of any specific mineral. Accordingly it was considered that the tolerances should be a percentage of the guarantee rather than a specific amount. Neither the matter of ratios nor the probable additions in excessive quantities being involved with iodine and iron it seems unnecessary for these to fix tolerances above as well as below guarantees.

Apart from bone meal, single materials sold for mineral nutrition are not subject to registration under the Act, but authority is given the Governor-in-Council by regulation to require labelling with appropriate particulars of the character and quality of products not subject to registration but included under the definition for "feeding stuff" previously quoted. Bone meal must be labelled with a guarantee of calcium and phosphorus, also the minimum protein and, if in excess of 5%, the maximum fat.

In addition to the labelling and guarantees outlined, there are other features of the new Act which have a bearing on mineral feeds. Its provisions apply to advertising as well as to sales, and penalties are provided where any feeding stuff, either in relation to the product or to the provisions of the Act, is labelled or represented incorrectly or in a manner likely to deceive any person. Furthermore, authority is provided to detain or seize any feeding stuff offered in violation of the provisions of the Act, and

withhold it from sale until it has been made to comply with requirements. These provisions should be very helpful in securing effective application of the law, as similar provisions in other laws have proven themselves to be.

The degree to which this legislation will serve its needed and intended purpose will depend as much upon those who are conducting experiments and researches in animal nutrition as upon those immediately responsible for its administration. An enlightened purchasing public is the most effective weapon against unethical and uneconomical trade practices, and at the present time feeders are greatly in need of enlightenment on matters of mineral nutrition. A knowledge of what is right and what is wrong, based on facts and not opinions which may differ, is necessary as a basis for legal action, for the most vigorous defence in cases of prosecution is usually made by the most deliberate and flagrant offender, who relies on his astuteness to escape conviction and penalty and to maintain himself in a shady but lucrative business. Whatever this society may be able to accomplish, therefore, in the way of providing to feeders and law enforcement officers uniform and widely supported data on animal nutrition, and particularly with regard to mineral nutrition, will be most welcome and helpful.

EIGHTH ANNUAL MEETING OF THE CANADIAN SOCIETY OF ANIMAL PRODUCTION (EASTERN SECTION)

The eighth Annual General Meeting of the Canadian Society of Animal Production (Eastern Section) was held at the Central Experimental Farm on June 16, 1937. The preparations and plans for the meeting were made by members of the executive and it was decided that in view of the importance and widespread interest of the mineral question in the live stock industry of Canada, this subject warranted the consideration of the Society.

The meeting, carried out under the chairmanship of the President, Professor A. R. Ness, Macdonald College, Quebec, was well attended and proved to be very successful. The papers presented at this session were assembled for publication in *Scientific Agriculture* by the incoming Secretary, Dr. McKenzie.

At the conclusion of the meeting the following officers were elected for the ensuing year:—

President: Professor A. R. Ness, Macdonald College, P.Q.

Vice-President: Professor R. G. Knox, Ontario Agricultural College, Guelph, Ont.

Ontario Director: Mr. L. E. O'Neill, Department of Agriculture, Toronto, Ont.

Quebec Director: Mr. S. J. Chagnon, Department of Agriculture, Quebec, P.Q.

Maritime Director: Mr. W. W. Baird, Experimental Farm, Nappan N.S.

Secretary-Treasurer: Dr. C. D. MacKenzie, Experimental Farm, Ottawa, Ont.

SWINE DISEASES IN WESTERN CANADA[1]

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A request for a representative of the Department of Agriculture to address the Canadian Society of Animal Production on, "Swine Diseases in Western Canada", passed to me, left me somewhat perturbed. It would be much easier to speak on one particular disease as we find it and know it, than on swine diseases in general as said to occur in Western Canada, and the very complex problems with which they are involved. There immediately come to mind questions such as: Do swine diseases in Western Canada differ much from those in Eastern Canada? If so, what diseases are peculiar to the West or to this or to that Province or locality? Are diseases of swine significantly more prevalent and of greater economic importance in the West? Is the disease picture dominated by any one particular or specific infectious disease, or a nutritional or mineral deficiency disease, or a problem relating to parasitical infestation; or, are swine more prone to disease in general under Western conditions of swine raising than in the East?

What follows is no more than an attempt to picture the disease situation and to have it discussed so as to indicate practical means of improving it and the terms on which swine husbandmen, *i.e.*, the farm and fieldmen, and scientific workers can best get together in a co-operative effort to solve the problems involved.

For several years past there have been rumours and reports of heavy losses in swine from diseases in Western Canada. Few of these reports have come to us direct from owners or breeders who had themselves experienced the losses reported. In several instances, where close inquiry was made, it was ascertained that no unusual losses had occurred.

During the past few months we have been in correspondence with persons who might be in a position to furnish information and state or define the chief problems in swine diseases that could be reviewed and intelligently discussed at this meeting.

Grateful acknowledgment is here made of the interest and assistance given by the Chief Veterinary Inspectors for the Provinces of Manitoba, Saskatchewan, Alberta, and British Columbia, and by veterinary officers and practitioners in the said Provinces.

Swine Diseases as Recognized at the Abattoirs

It may be profitable to first obtain a general view of the picture of swine diseases in Canada as a whole, and in this it may be helpful to first examine the figures covering hog carcass condemnations at the various packing house establishments, as furnished by the Meat Inspection Services of the Health of Animals Branch. It will suffice for this purpose to summarize the figures for the past three years.

[1] Presented at a meeting of the Canadian Society of Animal Production—Western Section, at the University of Saskatchewan, Saskatoon, June 29, 1937.

[2] Chief Pathologist, Health of Animals Branch, Dominion Department of Agriculture, Ottawa, Canada.

TABLE 1.—HOG CARCASS CONDEMNATIONS—1935–36–37

Condemnations	1934–35		1935–36		1936–37		Total	
	No.	%	No.	%	No.	%	No.	%
Tuberculosis	4,808	48.5	3,632	41.2	4,243	40.4	12,683	43.4
Arthritis	1,019	11.2	1,279	14.5	1,586	15.1	3,884	13.3
Pyaemia and Septicaemia	922	9.3	946	9.5	939	8.9	2,707	9.2
Pneumonia	801	8.0	785	8.9	759	6.3	2,345	8.0
Pleurisy	349	3.5	308	3.5	331	3.1	988	3.4
Emaciation	327	3.3	219	2.5	418	3.9	964	3.3
Peritonitis	228	2.3	301	3.4	441	4.2	970	3.3
All other causes	1,457	14.7	1,451	16.4	1,786	17.0	4,694	16.1
Total	9,911		8,821		10,503		29,235	
Total kill	2,862,125		3,812,898		3,821,602		9,496,625	
Per cent condemned		0.34		0.31		0.27		0.30

The year 1934–35 shows a total kill of 2,862,125 hogs, and carcass condemnations amounting to 9,911, or 342 per 100,000 (0.34%); for 1935–36, a total kill of 2,812,898; carcass condemnations, 8,821, or 310 per 100,000 (0.31%); and for 1936–37, a total kill of 3,821,602; carcass condemnations 10,503 or 272 per 100,000 (0.27%).

Tuberculosis accounted for nearly one-half of the total carcass condemnations. It should be noted here that the figures given refer to carcasses only and not to portions of carcasses. Carcass condemnations for tuberculosis are given as 48.5% for the year 1934–35; 41.2% for 1935–36, and 40.4% for 1936–37, showing a reduction of 8% in the three years.

The next disease in order of importance in respect to carcass condemnations is arthritis, which accounted for 11.2% in 1934–35; 14.5% in 1935–36; 15.1% in 1936–37, showing an increase of 4% in three years.

Pyaemia and septicaemia come next with an average of 9.2%; followed by pneumonia, 8%; pleurisy and peritonitis, 6.7%; and all other causes, combined, 16.1%. These figures obtain for the whole of Canada. What differences, if any, are to be found in the figures pertaining to diseases and condemnations of hogs arriving at Eastern and Western establishments, respectively? Table 2 gives the comparison for the year 1936–37.

TABLE 2.—HOG CARCASS CONDEMNATIONS—1936–37

Disease	Establishments				Total	
	Eastern		Western			
	No.	%	No.	%	No.	%
Tuberculosis	2,744	49.0	1,499	30.5	4,243	40.4
Arthritis	911	16.3	675	13.7	1,586	15.1
Pyaemia and Septicaemia	277	5.0	662	13.4	939	8.9
Pneumonia	237	4.2	512	10.4	759	7.3
Pleurisy and Peritonitis	392	7.0	380	7.7	1,381	7.3
Emaciation	227	3.9	172	3.5	418	3.9
All other causes	813	14.5	1,009	20.0	1,786	17.0
Total	5,594		4,909		10,503	
Total kill	2,017,434		1,804,168		3,821,602	
Per cent condemned		0.27		0.27		0.27

It is seen that the carcass condemnation percentage of the total kill is identical for the Eastern and Western establishments, namely 0.27%. In respect to the classified diseases, the condemnations for tuberculosis are considerably higher, as might be expected, in the East, 49%, than in the West, 30%. Arthritis accounts for 16.3% in the East and 13.7% in the West; these two diseases accounting for 65.3% in the East and 44.2% in the West, of all carcass condemnations. On the other hand, pyaemia, septicaemia, and pneumonia account for more condemnations in the West, 23.8%, than in the East, 9.2%. It is true that many Western hogs arrive at Eastern abatoirs, but the reverse does not take place, so that the Western figures apply only to Western hogs, and indicate the diseases found in those hogs as they reach the market.

Diseases of Swine as Occurring on the Farm and Premises Used for Hog-raising

To what extent do the diseases recognized at the abattoir represent the disease picture on the farm? Tuberculosis and arthritis are chronic, insidious diseases, slow in development. As a general rule these diseases commence early in the life of swine and are the cause, as previously mentioned, of 50% or more abattoir condemnations of whole carcasses (and for the major bulk of portions of condemned carcasses). It is evident, therefore, that these two diseases are of major importance in swine raising, and the cause of a heavy portion of the losses. In addition to these, the following may be named; hog cholera or swine fever, pneumonia, necrotic enteritis, haemorrhagic septicaemia, erysipelas, skin diseases (urticaria erythema), pyaemia, and abscesses; an important group of nutritional and deficiency diseases which include anaemia, goitre, rickets, paralysis, etc.; mange, and parasitic diseases caused by worm infestation.

No reliable data are available by which it would be possible to name the diseases of swine in Western Canada in the order of their incidence, sequence, and economic importance, or to indicate in figures the losses and mortality caused by each of them. The following brief statements have been derived and condensed from information obtained from Government officers, veterinarians, and other sources.

Manitoba

Haemorrhagic septicaemia, diseases of malnutrition, anaemia and calcium deficiency, round worm infestation, and sarcoptic mange are said to be the diseases of principal importance, and the cause of the heaviest losses.

Saskatchewan

Haemorrhagic septicaemia, swine erysipelas, infectious enteritis, coccidiosis, mange, and diseases of the new-born (goitre, anaemia), of which the two first named, haemorrhagic septicaemia and erysipelas, are seemingly of major importance.

Alberta

There have been more reported losses in swine from disease in Alberta, and more alarm expressed in this connection, than in any other Western Province. This may be due, in part at least, to the fact that more hogs

are raised in Alberta than in the other Provinces. The diseases of swine in Alberta reported or suspected do not differ in kind from those of Saskatchewan and Manitoba. Reports of heavy losses, especially in very young pigs on the premises where a large number of hogs are raised have been investigated, and while some have proved more or less correct, most of them have been found greatly exaggerated. If the mortality rate is somewhat higher in Alberta, no evidence has come to us of it being significantly higher.

British Columbia

In hogs raised and bred in the Province, it is said that few troubles are encountered, and that those are mainly attributed to faulty feeding, particularly of sows and young pigs. Large numbers of feeder hogs are imported, principally from Alberta, and go to the premises of garbage feeders. In many consignments the animals are said to be in a very unthrifty condition at the time of purchase and it is among these, following long train journeys and sudden changes from grain to a garbage diet, that heavy losses sometimes occur; which, under such circumstances, is not at all surprising.

Hog Cholera

It may be stated, first of all, that from all inquiries made and the information returned, there is no suggestion of a specific infectious and contagious disease, spreading from farm to farm or from district to district. Years ago, there were occasional extensive outbreaks of hog cholera or swine fever. This highly infectious, reportable disease is known all over the world. In many countries it is widespread and firmly rooted, and is the greatest problem in swine disease and prevention. In Canada, as a direct result of the Government policy and stringent regulations pursued for the past thirty or more years, it is never able to establish itself and is promptly eliminated by drastic means and the refusal to permit the use of cholera virus for vaccination purposes which serves to perpetuate sources of infection. The control and elimination of hog cholera has saved the swine industy in this country many millions of dollars, an achievement that is rarely or insufficiently appreciated.

Tuberculosis.

A disease of a more insidious nature, and therefore more difficult to detect and control, is tuberculosis. The progress made in eradicating this disease in cattle, by drastic means, has been and is highly satisfactory. Similar means have not yet come into practice for the control and eradication of swine tuberculosis which, in some quarters at least, appears to be becoming more prevalent. The primary cause of tuberculosis, as is well known, is the tubercle bacillus, of which there are three recognized types human, bovine, and avian. Swine are highly susceptible to the bovine and avian types, and to the latter is attributed the increasing incidence of swine tuberculosis; the source of infection being tuberculous poultry flocks, with which swine are so frequently in contact.

Swine Erysipelas and Arthritis

Swine erysipelas has for generations been known and dealt with in European countries as a swine disease problem of major importance. Until recent years this disease was regarded as an almost negligible factor

in swine raising in North America, where it appeared to occur only in its more benign form of urticaria, known as "Diamond Skin Disease". But lately it has attracted much more attention in the United States where it is becoming increasingly prevalent and appearing in its more acute and serious forms. Also in Canada, swine erysipelas is gaining ground and receiving more recognition. The disease may occur in either an acute or a chronic form, in which there is a wide range of clinical manifestations. A septicaemia is characteristic of the acute type of the disease which may end fatally within 24 to 48 hours of the onset of symptoms. The chronic type of the disease frequently involves the joints and the valves of the heart. It would be hazardous to express an opinion with regard to the incidence of the acute, septicaemic form of erysipelas in Canadian swine which is possibly confused with septicaemic conditions arising from other causes. Arthritis, mentioned before, accounts for a relatively high percentage of swine condemnations at the abattoirs, and it is quite possible that the greater number of these are co-related to or are actual manifestations of swine erysipelas. Fulton (Can. Jour. Res. 1933) has studied swine erysipelas as he observes it in the Province of Saskatchewan and has isolated from affected joints strains of the specific mirco-organism which causes this disease. A research study of arthritis in swine arriving at the abattoirs is being carried on by the Pathological Division, Health of Animals Branch. The vagaries in the development and course of swine erysipelas, the fact that the organism may exist for long periods of time almost as a harmless parasite and then assume an exalted virulence, and the varying susceptibility of swine to the disease make it a difficult one for diagnosis and control.

Infection is frequently associated with arthritis and rheumatoid conditions. But there are, undoubtedly, various conditions and health disturbances which predispose to or even originate the disease. Improperly balanced food rations with a lack of essential vitamins and minerals, improper housing with inadequate shelter and protection, constitutional weakness and an inherited predisposition are factors which singly or in various combinations may lead to rheumatic infection and arthritic disease. It has to be recognized that arthritis, although a frequent manifestation in the chronic type of erysipelas, may occur independently of that disease.

Haemorrhagic Septicaemia

A large group of diseases characterized by haemorrhages in the various organs and animal tissues, occurring in practically all species of farm animals and poultry, also in buffalo and some kinds of wild animals, and related to the presence in the circulating blood and tissues of a well recognized micro-organism, fall under the designation, "hemorrhagic septicaemia". The genus to which these micro-organisms belong has been named *Pasteurella*, hence pasteurellosis is another term for these infections and, in swine, is synonymous with haemorrhagic septicaemia and swine plague with which, for the most part, sporadic or enzootic swine pneumonia is included. The disease rarely, if ever, occurs as a true epizootic and, as a rule, only a few animals are affected at any one time in any given place or premises or in the same swine herd. It does occur, for the most part, as a complication of some other disease, such as, for example, hog cholera or swine fever; not as a primary cause but as a secondary and contributory

infection. The fact that it is so frequently encountered in association with some other highly contagious disease and so rarely occurs as an independent disease is often overlooked; also, the fact that pasteurella organisms may be found normally inhabiting swine and the soil and water to which swine have access. However, the virulence and invasive powers of pasteurella are changeable and may be exalted or lowered according to the susceptibility or resistance of the animals through which it passes. Nevertheless, it is important to keep in mind the fact that this infection in swine is much more likely to be a secondary and not a primary disease factor. For in spite of this it appears that haemorrhagic septicaemia is uppermost in the minds of many swine husbandmen and veterinarians; and that in the Western Provinces, and probably in the East as well, a diagnosis of haemorrhagic septicaemia is made on the farm more frequently than the diagnoses of any or all other swine diseases. It has become a habit apparently to designate swine pneumonia, acute or chronic, or in whatever type or form it is observed, as haemorrhagic septicaemia, and not only the pneumonias, but many other conditions associated with cough and respiratory troubles, enteritis, weakness, unthriftiness, etc. Some veterinarians go so far as to say that haemorrhagic septicaemia is the disease of principal importance occurring in their districts or provinces, and accounts for the bulk of the losses and mortality in swine. Very little evidence for such assertions and assumptions has been presented and it may well be questioned if the diagnoses of haemorrhagic septicaemia as usually made and the views commonly held in respect to the significance of this disease are in any way indicative of its actual occurrence and prevalence and of its true place in the picture of swine diseases.

Haemorrhagic septicaemia is said to occur in peracute, acute, subacute and chronic forms, thus covering a wide range of pathological manifestations: febrile, inflammatory, haemorrhagic, enteric and pneumonic. But fever and depression, petechiae and small haemorrhages, acute, chronic and necrotic pneumonia and enteric disease are by no means confined to or characteristic of only one disease, as, for example the disease termed haemorrhagic septicaemia. Similar manifestations feature a number of other diseases, and their observance in respect to disease diagnosis needs to be interpreted with caution and reserve, especially when considering haemorrhagic septicaemia as a disease entity in itself and not as a complication or an end-stage of another disease.

It must be remembered that micro-organisms of the pastuerella or haemorrhiagc septicaemia group are frequently found in healthy swine as harmless inhabitants; also, that they are or may be concomitant with other infectious and specific diseases, and that in the end-stages of these diseases they may rapidly multiply, invade the tissues and hasten death. The finding of these organisms in the blood and body tissues after death is of limited significance and affords no proof of their having originated or taken a leading part in the disease which had occurred.

Years ago haemorrhagic septicaemia or swine plague and hog cholera or swine fever were regarded as one and the same disease caused by the same organism, *P. suisepticus*. The discovery of the virus of hog cholera shattered that conception and all authorities are now in agreement that the septicaemia so frequently encountered in hog cholera is a secondary

complication to that disease. In 1934, we ourselves investigated an acute disease of hogs which had been reported as haemorrhagic septicaemia. Five outbreaks were studied and each one proved to be hog cholera, three of them in association with septicaemia *(P. suisepticus)* and one with enteritis *(B. suipestifer)*. These studies are given in detail by Dr. C. A. Mitchell in the Annual Report of the Veterinary Director General, March 31, 1935.

Granting the possible existence of haemorrhagic septicaemia as an independent disease, its occurrence as such is probably a rare thing, while its development as a secondary complication or follower of other diseases is comparatively frequent. When the diseases and factors on which this development so largely depends receive proper recognition it may safely be assumed that attention will revert and be focussed upon the primary, essential diseases and their causes instead of secondary invaders and contributors, and that haemorrhagic septicaemia will, in consequence, fall to a very much lower place in the rank of swine diseases.

Diseases of Nutrition

A great deal of the underdevelopment, poor physical condition, ill health and disease, especially in young pigs, can be attributed to faulty nutrition and parasitic infestation, one or the other or both together. Anaemia of young pigs is distinctly a nutritional disease apparently increasing in prevalence throughout the country. It means blood poverty. In this condition the blood corpuscles may be reduced to one-third, one-half or even one-quarter or less of their normal number and at the same time are deficient in mineral constituents, particularly iron compounds. This is due to inability of the blood forming tissues to produce normal blood as a result of malnutrition and deprivation of essential food elements. It leads to stunted growth and unthriftiness, loss of vitality and disease resistance, prepares a seeding ground for infection and, if severe and unchecked, causes high mortality.

Rickets is an example of one of the skeletal diseases associated with calcium and phosphorus deficiency; and goitre with an iodine deficiency. Certain forms of arthritis, crippling, and paralysis are connected with nutritional defects of one kind or another.

Parasitic diseases of swine have an important place in the picture under review and of these we need only name the more conspicuous: round worm infestation, coccidiosis, and sarcoptic mange.

There may thus be seen in this picture four principal groups of diseases which may be briefly stated as: 1, A group comprised of highly specific, infectious, independent diseases; 2, A group of more or less secondary infectious diseases, dependent upon various provocative factors; 3, Nutritional disease; and 4, Parasitic diseases. Those of the first group are constantly associated with their respective micro-organisms and viruses which, when they come in contact with and are taken into the system of a susceptible host, act directly. They may attack indiscriminately any or all animals of a susceptible species, with little regard for breed, age, sex, constitution, heredity, and environment. When the disease outbreak has spent itself or has been eradicated by drastic means the premises, after a thorough cleaning and disinfection and a short time interval, may be

restocked with little danger of a recurrence of the disease from within. A good example is hog cholera.

The second group, includes the diseases caused by infective agents which, year in and year out, are more or less present in the soil, in and about the pens, the buildings and environment. These micro-organisms continue for the most part a harmless existence even when harboured, carried and excreted by the animals themselves, but lie in wait, as it were, for conditions and opportunities which favour their multiplication and development, increase the susceptibility of animals liable to attack and indirectly promote disease. Their activation and the appearance or recurrence of the diseases in which they play their part depend upon local conditions and environment, exposure to sudden or severe climatic changes, improper housing, crowding, lack of sanitation, poor feeding, and deprivation of essential food constituents, malnutrition, constitutional weakness, the stress and fatigue of railway transportation and other factors which in various forms and combinations tend to lower health, vitality and normal disease resistance and provoke infectious processes.

The third group of diseases, the nutritional, depend only upon nutritional and physiological factors for their primary development and clinical manifestations, but frequently become linked up with diseases in the other groups. The relationship between malnutrition and infection is a delicate one, variable, and very difficult to define. Malnutrition may not directly result in infection but it may often be the deciding factor in respect to the course the infection may take—mild or severe.

Questions and Conclusions

In the foregoing conception of prevailing swine diseases in Western Canada and their causes, what is there of outstanding significance? And what are the actual problems?

Hog cholera is well taken care of and has ceased to be a major problem. There is, undoubtedly, the problem of swine tuberculosis, which depends largely upon tuberculosis in poultry. Then there is arthritis. The situation in respect to swine erysipelas is not clear and requires watching. Infectious abortion has not yet and, let us hope, will not come into the picture. But for the rest, which account for the bulk of unthriftiness, losses in sucking pigs and the general mortality on the farm, the problem can, I think, be clearly indicated and expressed in two words: Bad Management—bad husbandry! on the part of the man on the farm.

Throughout this Western country, and in the East as well, on the majority of hog raising farms, swine breeding, farrowing, care of the new born, feeding, housing, and all that pertains to good swine husbandry, appears to be carried on for the most part in a very haphazard way and with an unconsciousness of basic health requirements but an over-consciousness of disease.

How far does there come into the range of vision and practice of the average swine husbandmen the selection of breeding stock for constitutional fitness, for disease resistance, the special care required for the pregnant or farrowing sow and her large litter of sucklings; housing with an eye to construction, comfort, ventilation, sunlight, cleanliness, and sanitary needs;

feeding with a knowledge of nutritional values and requirements; clean, uncontaminated drinking water, suitable exercise pens, avoidance of overcrowding; and the ploughing and rotation of hog lots, etc. Is it surprising that when young hogs are weaned from their mothers' milk and fed on an exclusive diet of coarse grain, such as oats with a high content of fibre and hulls, and this apparently is being done very commonly, there follows a more or less severe intestinal irritation, indigestion, and state of malnutrition? Can it be expected that young feeder pigs will not suffer when they are subjected to a sudden change of diet from grain to garbage, and this again is a not uncommon practice? Is the average swine husbandman not more concerned with the administration of medicinal pills, condition powders, and disease remedies, the fetishism of a hypodermic syringe and needle and with what he thinks are short cuts to health, than with sound health principles and their intelligent practice? There are no short cuts to health, and there are no synthetic substitutes for health. There is an increasing and alarming tendency to trust to serums, vaccines, and preventive inoculations to overcome disease. For many of these widely used biological products and preparations there is little or no evidence of their value and efficacy, either protective or curative. Forgetful of the fact that many diseases are self-limiting, have run their course and have done all the damage they are capable of doing at the time a serum or vaccine is administered, the inoculations are often credited with results in which they have taken no part and to which they have no claim. Preventive inoculation and immunization have a place and a very valuable one in certain diseases, especially in what may be termed the acute, independent, contagious disease. Even so, it may be pointed out that no means of conferring immunity to a disease has ever resulted, in practice, in the eradication of that disease. Vaccination against hog cholera is fairly successful but in countries where it is practised, the infection is perpetuated, and in them it is hardly safe to attempt to raise pigs without vaccination; and so it is with many other animal and human diseases.

Nature never intended short cuts to health and does not tolerate them; when her biological laws and needs are neglected or defied she exacts a heavy penalty. Provocative disease may be and undoubtedly is one of Nature's means of getting rid of the weaklings, the constitutionally unfit, the impoverished and the unthrifty. In both human and animal races there develop sooner or later physically unfit members. Left to herself, Nature would suppress these and when they become so numerous as to endanger the race or species she employs very drastic means of eliminating them; and in achieving her end she does not hesitate to sacrifice many of the fit and efficient individuals. Everywhere there are germs lurking in the soil and in the animal body itself, living, for the most part, a harmless existence but subject, nevertheless, to call and provocation into disease activities. And these provocations, it may be stressed again, arise mainly from faulty living, breeding, feeding, and environmental conditions.

Swine are raised only for their commercial value. There is no profit in propagating the unfit or in raising animals in such a manner as to invite disease. Nature's drastic methods may be forestalled or not called into operation according to the attention paid to health laws and needs. It is true that the swine raiser may be so situated that he cannot afford the

cost of providing the necessary health requirements and equipment and at the same time make a profit when his hogs go to market. If this is so, then it is really too bad for the hog; and he is the victim of the conflict between the cost of his keep and health and the price of pork and bacon.

The laboratory services and specialist workers can aid and supplement the efforts of the man on the farm and in the field, but cannot substitute for him. The problem has to be solved in the field, not in the laboratory. From an angle of health—my theme is health, not disease, for health is a more important factor than disease—it is better and cheaper to start at the very beginning on a basis of health and build for health than to raise weaklings and then try every kind of substitute to keep them from falling down.

That there are swine disease problems is freely recognized. The independent, directly-acting diseases are relatively few and can be seen with fair clearness, and means for their control and eradication are not lacking. The dependent diseases are many and present a very confused picture. The view is obscured and the way of scientific approach obstructed by the many causes and conditions, varying in kind and degree, already pointed out and repeatedly stressed. For the most part, these can be and must be removed or corrected by the swine husbandman himself and no other. The problems will then be made clear and many of them without a doubt, will disappear. What is left will be exposed in distinct outline and significance and the way opened for scientific workers to make their attack and offer effectual aid, co-operation and contribution.

THE RELATIVE VITAMIN A CONTENT OF THREE VARIETIES OF NORTH WESTERN DENT CORN—MANITOBA-GROWN RED, YELLOW AND AMERICAN YELLOW

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[Received for publication August 9, 1937]

Corn has been recognized for many years as a very popular grain in poultry rations whether feeding for growth, egg production, or for fattening. According to Fraps (2) corn is readily digested and is also very palatable. A number of investigators have shown that yellow corn has higher feeding value than white corn because it contains liberal amounts of the growth-promoting vitamin A. "Kempster (6) found that a ration containing 56% of yellow corn was superior to a similar ration containing the same proportion of white corn," when fed to laying hens. Kempster and Henderson (7), the Indiana Experiment Station (5) and the Poultry Husbandry Department of the University of Manitoba (8) have conducted experiments demonstrating the superiority of yellow corn over white corn in rations for growing chicks. Recent vitamin A studies by Herner (4) clearly demonstrated the vitamin A deficiency in white corn when fed to chicks. Lack of growth, sore eyes or xerophthalmia, and large amounts of urates in the kidneys and ureters were symptomatic of this deficiency.

Yellow corn also contains xanthophyll and carotene, both of which may be associated with vitamin A. These produce a rich yellow colour in the skin and shanks of yellow-legged chicks; a rich yellow color in the yolk of eggs; and a yellow fleshed carcass in market birds. However, it is largely for its growth promoting vitamin A content and its value in preventing disease or establishing resistance to it that yellow corn is preferred to white.

The use of corn has been more extensive in the warmer southern latitudes and in milder climates where it is easily grown than in the colder northern latitudes with their short growing seasons, dangers of frost and difficulty in getting maturity. The use of corn in these colder areas is also further restricted on account of transportation and importation costs, making it too expensive for economic poultry feeding. Nevertheless, restricted though the use of corn may be, many manufacturers and distributors of poultry feeds in the colder climates desire to have a certain amount of corn in their feed mixtures because of its high feeding value. However, the addition of imported corn generally raises the cost of poultry rations considerably, and an effort is being made, therefore, to encourage the use of corn grown locally rather than the imported product, in order to hold down the cost of mash and grain mixtures which poultrymen are using.

In the Prairie Provinces of Western Canada, the growing of corn has been confined very largely to the southern districts because of the longer growing period and the lesser frost hazard than farther north. While the amount grown and available for feeding purposes is rather limited, yet with the improvement of varieties and the shortening of the period of

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maturity the amount grown has increased, and if there is a good market it will still further increase from year to year. Since the amount grown locally has always been rather limited the imported corn has formed the chief source of supply, and on a competitive basis preference has been given to the imported product. To a certain extent, this has been due to the lower moisture content of imported corn and the lower risk in storing and handling it. Drying will, of course, eliminate this objection. In addition, the vitamin A content of the locally grown corn has heretofore been an unknown quantity, and until assurance can be given as to its relative growth promoting properties it may have to continue taking second place to the imported corn.

EXPERIMENTAL METHODS

In order to establish a definite rating as to the growth promoting value or the vitamin A content of Manitoba grown corn the Poultry Husbandry Department of the University of Manitoba undertook a special 8-week feeding experiment in January, 1937. The test was confined to two varieties of corn grown in Manitoba, viz., a red variety of Northwestern Dent and a yellow variety of Dent known as Falconer, and a sample of yellow commercial feed corn of the Northwestern Dent variety imported from the United States.

TABLE 1.—FORMULAE OF RATIONS AND PROTEIN CONTENT

Lot No.	1	2	3	4	5	6	7	8	9
	lbs. or %	lbs. or %	lbs. or %	lbs. or %	lbs. or %	lbs. or %	lbs. or %	lbs. or %	lbs. or %
American Yellow Corn, ground fine	60	40	20	–	–	–	–	–	–
Manitoba Yellow ground fine	–	–	–	60	40	20	–	–	–
Manitoba Red ground fine	–	–	–	–	–	–	60	40	20
White Corn, ground fine	–	20	40	–	20	40	–	20	40
Oat Middlings	21	21	21	21	21	21	21	21	21
Skim-milk Powder	10	10	10	10	10	10	10	10	10
Meat Meal (60% protein)	6	6	6	6	6	6	6	6	6
Lime Grit	1	1	1	1	1	1	1	1	1
Charcoal	1	1	1	1	1	1	1	1	1
Salt	1	1	1	1	1	1	1	1	1
Total	100	100	100	100	100	100	100	100	100
Protein Content	17.35	17.05	17.68	17.71	17.64	17.71	16.20	16.64	17.08

The feed formula was drawn up as shown in Table 1 with the basal ration as indicated and white and yellow corn interchanged in order to keep the total amount of corn in each ration constant or at the same level. With the basal ration completely void of vitamin A and with yellow corn as the only source of this vitamin, feeding it at the three levels provided an opportunity to study the effect of adding larger amounts and also to make comparisons as to the growth promoting value of each of the three varieties at three different levels. It will be noted in Table 1 that the protein level of all diets was slightly below that required for normal growth of chicks as given by Card, Kirkpatrick (1). The object of this was to have the chicks slightly more responsive to the growth promoting factors,

apart from that of protein, and thus be able to measure the effect of vitamin A, as a factor, more accurately. According to these figures, the protein content of the ration containing the particular sample of red corn fed to lots 7, 8 and 9 was considerably lower than that of the other two samples.

In regard to vitamin D, ample provision was made for this by giving each lot 20 minutes daily irradiation under the mercury quartz lamp.

No control lot was used because earlier studies furnished abundant evidence of a complete lack of vitamin A in a diet composed of 78% of white corn with the other ingredients and the protein and mineral supplements almost identical to those used in this experiment both as to nature and amounts.

On January 15, 1937, 270 newly hatched S.C. White Leghorn chicks were leg banded, weighed individually and divided into 9 lots of 30 each. An attempt was made to equalize the mean weights of all lots. These chicks were brooded in battery brooders under as uniform conditions as possible. The ration fed to each lot is indicated in Table 1. They were given water to drink *ad lib.* A sufficient amount of mash for each lot was mixed at the start to carry the chicks up to 8 weeks of age and an ample supply was kept before them continuously.

All the chicks were weighed individually each week and these weights recorded, as well as the amount of food consumed each week.

Some difficulty was experienced with cannibalism, and as a result the later mortality in a few of the lots is higher than it should be.

DISCUSSION

This experiment was designed primarily for the purpose of making comparisons as to the vitamin A content of three varieties of corn with the growth promoting factors as the chief index and deficiency disease symptoms as secondary factors. Besides providing a wider range for comparison the thought was that with yellow corn as the source of the vitamin and feeding it at 20, 40 and 60% levels, respectively, might also provide information as to what quantity would furnish the required amount of vitamin A in an otherwise A free ration.

A review of the data on average weights as presented in Table 2 shows a marked similarity in growth in all lots. The trend, however, seems to be towards accelerated growth when more corn is added. The

TABLE 2.—MEAN LIVE WEIGHT AT 8 WEEKS AND THEIR STANDARD ERROR

Lot No.	Males	Females	Males and females (weighted mean)
I	412.50 ± 20.34	344.68 ± 16.09	378.59 ± 12.97
II	382.08 ± 18.36	370.35 ± 17.20	376.22 ± 12.66
III	361.00 ± 20.34	349.00 ± 16.61	355.00 ± 13.14
IV	386.36 ± 19.40	357.50 ± 20.34	371.93 ± 14.06
V	400.64 ± 17.20	379.81 ± 19.40	390.23 ± 12.97
VI	414.33 ± 26.27	346.05 ± 15.61	380.19 ± 15.28
VII	416.58 ± 18.36	360.90 ± 20.34	388.74 ± 13.78
VIII	400.28 ± 24.33	348.37 ± 16.09	374.33 ± 14.58
IX	392.00 ± 20.34	335.31 ± 16.09	363.65 ± 12.97

exception to this is lot 4, and the reason would seem to be a severe outbreak of cannibalism which started the third week and raged till the fifth week, taking a death toll of 6 chicks in this period and also adversely affecting the growth of the survivors. Lot 7 passed through a similar experience, and while the mortality was high, preventive measures stopped it almost immediately and the effect on the survivors was not so disastrous. Cannibalism also caused some mortality in lot 6, but was brought under control very quickly. There was no evidence whatever of any pathological condition due to vitamin A deficiency.

In view of the fact that males grow faster than females and since the proportion varies in each lot, it is necessary to make adjustments as to the influence of sex on these weights. Furthermore, since diets differ as to variety of corn and also as to rate of feeding, it becomes necessary to make further analyses for variances as to these two factors.

A statistical analysis has, therefore, been made covering all these factors. In Table 2 are presented the mean live weights of the chicks at 8 weeks of age and their standard error. While there is considerable variation in these weights, yet the analyses presented in Table 3 and 4 would indicate that when the effect of both diet and sex are considered, there is no significant difference between lots. In making these analyses the method outlined and presented by Titus and Hammond (8) was followed.

TABLE 3.—PRIMARY ANALYSIS OF LIVE WEIGHTS

Source of variation	d/f	Sums of squares	Variances (mean squares)	Standard deviations
Sub classes	18	142 388	7,910 44	88 91
Error	199	824.373	4,142.57	64.36
Total	217	966 761	–	–

TABLE 4.—FURTHER ANALYSES OF LIVE WEIGHTS: THE EFFECT OF DIET AND SEX

Source of variation	d/f	Sum of squares	Variances (or mean squares)	Standard deviations
Diet	8	23,631.88	2,953.98	54.35
Sex	1	86,582.37	86,582.37	294.25
Interaction (sex and diet)	8	24,803.88	3,100.48	55.68
Error	199	824,373.00	4,142.57	64.36

Since there appear to be differences in the effectiveness of different rates of feeding the Manitoba Red and American Yellow, still further analyses were made by applying the Yates (10) method of fitting constants. This method was used to test the significance of difference between the rates of feeding. The results of these analyses are presented in Table 5, and obviously show that there are no significant differences between the rates of feeding these three varieties of corn.

TABLE 5.—ANALYSES OF VARIANCES FOR RATES OF FEEDING WITHIN VARIETIES

——	*DF*	*SS*	*MS*	*F*
Manitoba Red— Between Rates	2	6,034.30	3,017.15	.7283
Manitoba Yellow— Between Rates	2	4,526.98	2,263.49	.5464
American Yellow— Between Rates	2	7,501.32	3,750.66	.9054
Error	199	824,366.70	4,142.55	

These methods of variance analysis, therefore, indicate that there is no significant difference in the mean weights, at the conclusion of the experiment, when sex, variety of corn and rate of feeding it are considered.

However, these analyses show what appear to be trends that the vitamin A content of the 20% American corn in the ration fed to lot 3 is probably lower than that of all the other rations and definitely lower than that of the rations fed to lots 2, 5, 6 and 7. It would also seem that 20% of the Manitoba yellow and Manitoba red, fed in the other two rations provided sufficient vitamin A to bring the rate of growth up equal to the 40 and 60% levels of these varieties. These investigations, therefore, indicate that 20% of the Manitoba-grown corns provided sufficient vitamin A and suggest the possibility of 20% American yellow corn not being quite adequate for these requirements. Hauge, Carrick and Prange (3) reported that 25% of American yellow corn in the ration appeared to meet the vitamin A requirements of growing chicks up to 10 weeks of age.

Whatever variations and trends there are in the average weights of these chicks at 8 weeks of age cannot be attributed to the protein content of the ration because earlier protein studies established, first, that the protein requirements of a normal growth are higher than that contained in these rations, and, second, that small differences like these in protein content do not influence the rate of growth one way or the other. With the genetic make-up the same in all the chicks, and all other factors the same, it would

TABLE 6.—MORTALITY RECORD

Lot No.	Number of chicks				Mortality		
	At start	At finish			1st week	Later	Total
		Males	Females	Total			
1	30	10	16	26	3	1	4
2	30	12	14	26	3	1	4
3	30	10	15	25	5	-	5
4	30	11	10	21	3	6	9
5	30	14	11	25	4	1	5
6	30	6	17	23	3	4	7
7	30	12	10	22	2	6	8
8	30	7	16	23	5	2	7
9	30	10	16	26	3	1	4

seem that apart from lot 4 the variations or trends can be attributed only to the vitamin A content.

In respect to yellow pigmentation in the skin and legs of the chicks there was no noticeable difference in any of the lots at 8 weeks, either as to amount or density.

CONCLUSIONS

The evidence shows: (1) that both Manitoba Yellow and Manitoba Red corn are fully equal to American Yellow in vitamin A content; (2) that 20% of either of these two varieties provided sufficient vitamin A in these rations to promote healthy growth; (3) that the addition of more corn of these two varieties did not produce any acceleration of growth. It might be added that there is a suggestion that 20% of American Yellow corn did not furnish quite as much vitamin A as the same amount of each of the Manitoba varieties, and a slight indication that this amount of American Yellow corn did not meet the vitamin A requirements of growing chicks up to 8 weeks of age.

The data on the protein content of these rations suggests the possibility of the Manitoba Red variety being lower in protein than the other three varieties in all three rates of feeding.

ACKNOWLEDGMENTS

The author is indebted to Dr. C. H. Goulden for advice and help concerning statistical analysis of data and to Dr. A. D. Robinson for the chemical analysis of the feeds.

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THE PROBLEM OF DETERMINING THE DIETARY CALCIUM AND PHOSPHORUS REQUIREMENTS OF ANIMALS[1]

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In spite of the increasing attention to and realization of the importance of minerals in the nutrition of farm stock, and the rather voluminous literature already available on the subject, there is still very little accurate quantitative data regarding the requirements of animals for the two mineral elements needed in largest amounts, calcium and phosphorus. The levels of these two elements recommended for the rations of the various classes of stock under various conditions of production are actually based on data much less satisfactory than that on which our "feeding standards" for the primary organic dietary constituents have been calculated. In fact, one has only to discuss the question of minerals with feeders and even with some to whom feeders look for advice, to realize how unsatisfactory is the general understanding of the fate in the animal body of dietary calcium and phosphorus; of the principle roles which they play in nutrition; the effects or results of their deficiency; and the gross symptoms which such deficiencies show. It is, perhaps, in part, a result of this that many extravagant claims for the benefits of mineral feeding have so long been unchallenged, and the sale of expensive mineral mixtures flourished so extensively during the past few years.

Admittedly, there is much yet to learn about the problem of mineral nutrition, but on the other hand there is enough known already to answer many of the simple questions on the subject, and it may be worth while to summarize briefly a few of the main facts of calcium and phosphorus metabolism as a means of better appreciating the difficulties of research on this subject and also to give some basis for interpreting the results of such studies.

One of the first essentials in any study of animal requirements is a satisfactory measure or criterion of adequacy. The energy which must be supplied an animal for maintenance can be determined by a measurement of the heat lost from the body under certain defined conditions. The corresponding criterion of protein sufficiency is the loss of endogenous nitrogen from the body. Procedures for such determinations, though exacting, are well understood and reasonably straight forward. Production demands in excess of maintenance are indicated more or less directly by the body weight increases or productions made. Inasmuch as the end products of the metabolism of the organic nutrients are eliminated through paths different from that of undigested dietary residues or else are in such form as to be easily differentiated from them, a picture of their metabolism with reference to adequacy of ration intake can readily be obtained.

In the case of calcium and phosphorus, however, such criteria are for the most part quite unsuitable. They may even be misleading. For

[1] An abstract of a paper delivered at the eighth annual meeting of the Canadian Society of Animal Production (Eastern Section) held at the Central Experimental Farm, Ottawa, Canada, June 16, 1937.

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example, energy balances are useless, for these elements do not enter into the energy equilibrium of the body. Urinary excretion us but a minor fraction of the endogenous loss. These elements are excreted in the same form chemically as they were ingested, and hence endogenous, exogenous, and dietary residue fractions of the fecal excretions cannot be separated. Absorption from and re-excretion into the gut are in part governed by factors unrelated to dietary intake. The calcification and storage of these elements in the skeleton and their removal therefrom are processes proceeding more or less continually and also proceed in many cases quite independently of dietary intake. The quantity and ratio of calcium and phosphorus in the diet; the acidity of the intestinal tract; the presence of vitamin D; the activity of the endocrine system, especially the thyroid and parathyroids; and the individual status of the animal as to health, pregnancy, and milk or wool production are all factors influencing the metabolism of these two elements.

In the final analysis, the status of the mineral nutrition (calcium and phosphorus) depends on a balance between absorption from the diet, excretion from the body, and the rate of deposit in and withdrawal of these elements from the skeleton. Of these, the last named is by far the most important under normal conditions. After all, it is the condition of the "reservoir" that is important. Temporarily, it may be low with no harmful results to the animal. This, in fact, is the normal state of affairs at certain times such as early lactation, while at other times there will be rapid storage.

Since it is the status of the skeleton storage that is the final criterion of the adequacy of the calcium and phosphorus nutrition, the requirements for these elements must be determined with reference to the condition of this storage. Dietary intake is not a criterion, excepting that over long periods it may be too low. The blood picture is likewise unreliable unless followed long enough to smooth out the daily fluctuations in phosphorus content. In fact, the only accurate method involves the slaughter of animals carried on a known dietary regime and a direct determination of the condition of the mineral content of the bones. To date, some such tests have been carried out, but much more work is needed before anything comparable to "standard requirements" can be hoped for. "Slaughter" tests are slow and exceedingly expensive for the larger animals, and much evidence can be cited that there are marked species differences so that the work must be done on the particular species of animals to which the results are to be applied.

It hardly seems possible, therefore, at the present time to answer the oft raised question of how much calcium and phosphorus a diet should contain, beyond the very general findings from observation of the behavior of animals and a limited amount of experimental data which may be summarized tentatively as approaching, as minimums, the following percentages of the total dry matter of the ration:

	Calcium	*Phosphorus*
Cattle and sheep	0.40 to 0.20%	0.35 to 0.20%
Pigs	0.60 to 0.30%	0.45 to 0.25%
Poultry	0.75 to 0.40%	0.50 to 0.35%

In general, the requirements will decrease with age or maturity, and obviously may vary widely with local conditions and with individual animals.

Considering the character of feeds normally used for these classes of stock, it is quite generally accepted that the problem of supplemental mineral feeding in as far as it relates to dairy cattle usually concerns phosphorus, while with hogs and poultry it is calcium which must be supplied. The form in which they are fed is relatively immaterial,— most sources being equivalent per unit of the element contained.

THE BORON CONTENT OF APPLE TISSUES AS RELATED TO DROUGHT SPOT AND CORKY CORE[1]

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[Received for publication August 23, 1937]

In conjunction with the work of McLarty (14, 15) and McLarty *et al.* (16) on the control of drought spot and corky core of apple in British Columbia, the boron content of the experimental plants was determined by chemical analysis. This paper summarizes the results obtained to date.

The position of boron as an essential element for plant growth has been well established by the works of Brenchley (5), Warington (19), Johnston (13), Haas (8), and many others. They have shown that boron is essential for normal growth and that its deficiency results in physiological disorders which are characteristic for the plant under experiment. In the apple it has been shown by McLarty (15) and Davis (10) in Canada, Atkinson (3) in New Zealand, and Jamalainen (11, 12) in Finland, that a disorder or disorders known variously as drought spot, corky core, cork, internal cork, brown heart, poverty pit, or crinkle are due to a deficiency of this element.

The quantitative determination of boron in plant tissues has been made by several investigators. Agulhon (1) found that the boron concentration in the stems and leaves of fir trees ranged from 7 to 14 p.p.m. while in the leaves of figs it was 79 p.p.m. Bertrand and De Waal (4) have reported on the comparative amount of boron found in 21 plants grown on the same soil. On a dry weight basis this ranged from 12 p.p.m. for barley to 571 p.p.m. for poppy. In a recent publication Eaton (7), reported that, in 127 samples of citrus and walnut leaves collected from various sources in California, the boron content varied from 35 to 1522 p.p.m. He showed further that its concentration varied widely in different organs of the same plant and even in the different parts of an individual organ such as the leaf. Piper (17) in Australia found that the boron content of normal apple fruit ranged from 12 to 30 p.p.m.

The comparative amounts of boron in plants affected with, and free from, deficiency symptoms has not been extensively determined. With internal cork or corky pit of apple Askew (2) found that the boron content of fruit from severely affected trees was 3 p.p.m. whereas that from the healthy was 12 p.p.m. The comparison in the leaves was 9 p.p.m. and 18 p.p.m. respectively. With brown heart of turnip, Hill and Grant (9) found that the diseased tubers contained 0.005% and the healthy 0.035% boron as B_2O_3 in the ash.

ANALYTICAL PROCEDURE

Sampling of Material

Most of the samples were collected from the 23-acre orchard which is being used as an experimental block in the study of these diseases. In addition, samples from other orchards both in British Columbia and

[1] Paper presented at the Annual Convention of the Canadian Chemical Society at Vancouver, B.C., June, 1937.
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Eastern Canada were included. Samples were taken of both tree tissues and of the soil in which the trees were grown. The parts of the tree used were: one year old twigs, mature leaves, and mature fruit. The twigs and soil samples were collected during the dormant period.

The twigs were cut into one inch lengths and dried at 75° C. to constant weight. The leaves were similarly dried. The fruit was cut into small slices and received a preliminary drying at 35° C. for approximately two weeks, after which the pieces were dried to constant weight at 75° C. The dried materials were ground, replaced in the oven at 75° C. for a further period of 24 hours and then cooled in a desiccator over calcium chloride. From each sample thus prepared two portions of approximately 30 gm. weight were taken and the analyses were made in duplicate. Each portion was weighed exactly and on this weight all calculations for the amount of boron present were based.

In securing the soil samples cores were taken with a 2-inch auger from 4 positions, each approximately 6 feet from the tree whose soil was to be tested. These cores were taken to depths varying from 12 to 24 inches. They were thoroughly mixed together and from the mixture a convenient sized sample (approximately one pound) was used. Each sample was air dried at room temperature and its moisture holding capacity was determined by the settling volume method (20). From the air dried sample an amount of soil was weighed which would hold 60 gm. of water at moisture holding capacity. It was on this weight of soil that the final calculations for the amount of boron present were based. The sample was shaken with 1500 ml. of distilled water and the mixture saturated with carbon dioxide by bubbling a rapid stream through it for 15 minutes. During this period the mixture was occasionally shaken. It was then allowed to stand in a closed container over-night. From this a clear soil extract was secured by drawing off the super-natant solution through a Livingston atmometer. A 1-litre aliquot was taken and evaporated to a convenient volume. This concentrated solution was then analyzed by the same method as used for the plant tissues after these had been ignited and taken up with water.

Method of Analyses

Several methods of analyzing for boron were tested. These include those developed by Bertrand and Agulhon (23), Brown (6), Smith (18), and Wilcox (21, 22). The method finally adopted was similar in almost all respects to that described by Wilcox. The method used was as follows.

The dried portion of the sample was removed from the desiccator and weighed, as noted above. It was thoroughly mixed with 5 gm. of finely powdered lime and ashed in a nickel crucible at dull red heat (400° to 450° C.) for 24 hours. The ash was transferred to a beaker and neutralized with concentrated hydrochloric acid. A slight excess (1 to 2 ml.) was added and the solution evaporated almost to dryness on a water bath. The partially dried residue was rinsed with methanol into a 350 ml. Erlenmeyer flask (hereafter referred to as the decomposition flask) and the volume made up to 50 ml. with additional methanol. To insure acid and anhydrous conditions in the solution during the subsequent distillation 1 ml. of concentrated hydrochloric acid and 10 gm. of anhydrous calcium chloride were added. The decomposition flask was then connected on one

side to a condenser and on the other to a reservoir which contained 250 ml. of methanol. The lead from the reservoir was carried well below the surface of the liquid in the decomposition flask. The reservoir and decomposition flask were placed on water baths. A receiving flask, containing 15 ml. of 0.5 *N* NaOH and to which was fitted a U-shaped trap containing 3 to 4 ml. of the same, was connected to the delivering end of the condenser. In operation, the rate of distillation of the alcohol from the reservoir was controlled so that no escape of methyl borate was possible through the system. When 250 ml. of distillate had collected in the receiving flask the distillation was deemed complete. The contents of the trap were rinsed into the receiving flask with distilled water. This solution was then made alkaline to phenolphthalein, if not already so, with 0.5 *N* sodium hydroxide, and an excess of 10 ml. of this reagent was added. Methanol was now distilled off and when only a few millilitres remained in the flask, the extract was transferred to a copper beaker, evaporated to dryness, and ignited at a red heat to destroy any organic matter. The residue was washed into a glass beaker, made acid by the addition of 6 *N* sulphuric acid, and boiled for 2 to 3 minutes in order to expel carbonic acid. When cool the solution was titrated.

The titration was by the electrometric method. The solution was brought to neutrality by the addition of dilute standard sodium hydroxide. After the reading on the burette containing the dilute standard alkali (0.02 *N*) had been taken, a gram of mannitol was dissolved in the sample and the standard sodium hydroxide again added until neutrality was reached. The amount of boron in the sample was determined by the amount of alkali required to neutralize the complex acid formed by the combination of the mannitol with the boric acid present in the solution.

Blanks were run through all stages of the procedure, and the necessary correction made in calculating the amount of boron in the sample.

A boron free glass (Kavalier) and copper beakers were used in order to avoid contamination from the slightly soluble boron trioxide present in many chemically resistant glasses.

Tests on the Method

1. *Titration Blanks for Soil Analysis*

Two hundred and fifty millilitres of distilled water were made slightly acid by adding a drop or two of 6 *N* sulphuric acid and boiling the solution to expel carbon dioxide. This solution was titrated by the complete electrometric method outlined above. For each lot of standard alkali used four such blanks were tested. The average of these results was used in making the necessary adjustment in all sample analysis. An example of such a titration blank was as follows: The amounts of alkali necessary to neutralize the solutions were found to be:

	(1)	0.09 ml. of standard 0.024 *N* alkali.
	(2)	0.11 ml. of standard 0.024 *N* alkali.
	(3)	0.12 ml. of standard 0.024 *N* alkali.
	(4)	0.10 ml. of standard 0.024 *N* alkali.
Average		0.10 ml. of standard 0.024 *N* alkali.

2. *Titration Blanks for Plant Material Analysis*

For each lot of reagents two complete check analyses were made. The average of these was used in making the necessary adjustments on sample analysis. During the course of this investigation impurities due to reagents varied from the equivalent of 0.30 to 0.70 ml. of 0.024 *N* alkali.

3. *Percentage of Recovery from Solutions of Known Boron Content*

Six complete analyses were made on a standard borate solution containing 0.96 mg. of boron per 10 millilitres. The recovery on these tests varied from 0.841 to 0.969 mg. of boron or an average recovery of 94.36%.

4. *Variations in Individual Samples*

Each sample was analyzed in duplicate, and data on the variations occurring in such analyses are presented in Table 1. These examples were chosen to give an indication of the accuracy to be expected at the different ranges of boron concentration.

TABLE 1.—RESULTS OF DUPLICATE DETERMINATIONS OF BORON IN SAMPLES TAKEN IN ROUTINE LABORATORY WORK

Sample No.	Portion A p.p.m.	Portion B p.p.m.	Difference p.p.m.
A18	211.0	215.0	4.0
L15	28.3	27.7	0.6
M11	19.1	22.1	2.0
M36	14.0	12.6	1.4
M36a*	13.0	13.6	0.6
D2	13.3	13.1	0.2
AFM12	12.2	12.8	0.6
M33	11.0	11.4	0.4
ATK38	7.4	7.2	0.2
ATQ1	6.0	6.0	0.0
A9	2.1	2.3	0.2

* Same as M36, but analyzed one year later.

RESULTS

Boron analyses of twigs from trees in the experimental orchard which were variously affected with drought spot and corky core are given in Table 2. In Table 3 are presented analyses of twigs, leaves, and soils from diseased trees in the experimental orchard which had received varying amounts of borax and boric acid, and from healthy trees in the laboratory orchard. A comparison is made in Table 4 of the boron contents of diseased and healthy apple tissues from various parts of Canada.

DISCUSSION

The results presented in the foregoing tables indicate a definite correlation between a low boron content in tree tissues and a high incidence of drought spot and corky core, and likewise a correlation between high boron content and absence of disease. Since the materials used in the analyses were taken almost entirely from British Columbia orchards, these correlations may be considered as being applicable only to this particular area. The analyses of materials secured from other fruit growing areas have not been sufficiently extensive to justify any conclusion that this relationship always maintains. In general, where no disease is present, the boron content of the twigs is at least 14 p.p.m. and where the diseases are severe, the boron content is below 10 p.p.m. Between 10 and 14 p.p.m. some disease may be expected.

TABLE 2.—THE RELATION OF THE BORON CONTENT OF TWIGS TO THE PERCENTAGE OF DROUGHT SPOT AND CORKY CORE

Tree No.	Variety	Drought spot	Corky core	Boron, p.p.m. dry weight
		%	%	
HH10	McIntosh	0	0	15.25
JJ12	McIntosh	0	0	14.59
AA25	McIntosh	0	0	14.17
JJ9	McIntosh	28	28	13.62
FF13	McIntosh	20	72	13.31
JJ24	McIntosh	33	–	12.51
LL9	McIntosh	80	48	11.46
BB23	McIntosh	0	0	11.45
CC25	McIntosh	0	0	11.44
DD12	McIntosh	84	52	10.57
HH18	McIntosh	24	20	10.21
X11	McIntosh	100	100	9.30
II17	McIntosh	100	92	8.69
KK21	McIntosh	92	68	7.97
GG16	McIntosh	64	44	7.61
W11	McIntosh	96	46	6.50
W10	McIntosh	100	90	6.49
EE16	McIntosh	100	90	6.31
GG26	McIntosh	20	20	6.22
HH26	McIntosh	100	100	6.11
GG25	McIntosh	80	100	5.71
EE23	McIntosh	56	100	5.63
EE17	McIntosh	100	100	4.89
KK27X	Wealthy	48	36	10.81
FF25X	Wealthy	30	90	9.95
II24X	Wealthy	72	96	8.90
JJ23X	Wealthy	92	96	8.44
HH25X	Wealthy	84	96	5.16
JJ27	Delicious	0	0	14.00
KK27	Delicious	0	0	13.75
HH29	Delicious	36	0	12.92
EE31	Delicious	10	0	12.64
II28	Delicious	0	0	11.22
FF29	Delicious	12	0	10.88
GG29	Delicious	20	0	10.38
EE8	Duchess	16	20	13.91
FF8	Duchess	64	96	11.61
II7	Duchess	100	100	9.49
LL5	Duchess	72	100	8.72
HH7	Duchess	100	100	8.44
KK6	Duchess	100	100	7.84
JJ8	Duchess	36	72	7.61

The results on soil analyses do not show as clear a correlation. Where the boron content of the soil was relatively high, such as was found in the plots receiving the applications of either boric acid or borax, the relation of these concentrations to reduction or abolition of the diseases was definite. Where the boron content of the soil was low as was found around all the check trees, some of which were healthy and some diseased, no correlation can be established. The reason why this should be, is not known. It is possible that the method used in making the soil extractions did not bring into solution all the boron available to the trees. On the other hand McLarty's observations (14) that diseased trees suffer from heavy rootlet

killing, may offer an explanation for this absence of correlation. It may be that trees on which rootlet injury has occurred have been weakened in their abilitv to absorb this element.

TABLE 3.—COMPARISON OF THE BORON PRESENT IN LEAVES AND TWIGS OF THE McINTOSH APPLE, AND SOILS FROM TREATED PLOTS

Tree No.	Treatment March, 1936	1935		1936		Boron p.p.m. dry weight		
		DS*	CC	DS	CC	Leaves	Twigs	Soils
Departmental Orchard, Kelowna								
		%	%	%	%			
J18	¼ lb. Boric Acid	48	48	8	0	15.1	10.4	0.98
K17	½ lb. Boric Acid	76	64	0	0	21.6	11.8	0.55
L16	1 lb. Boric Acid	90	70	0	0	19.1	8.7	0.99
M15	2 lb. Boric Acid	82	38	0	0	19.5	11.4	1.69
N14	4 lb. Boric Acid	62	28	0	0	26.6	15.5	2.32
J17	¼ lb. Borax	68	48	10	0	15.0	12.0	0.59
K16	½ lb. Borax	48	8	0	0	13.3	9.5	0.46
L15	1 lb. Borax	00	00	0	0	28.0	13.8	0.49
M14	2 lb. Borax	84	32	0	0	20.1	12.8	0.92
N13	4 lb. Borax	56	28	0	0	23.6	21.8	1.53
J15	Check	56	00	8	18	10.2	6.0	—
M12	Check	9	9	78	21	14.1	6.0	—
K18	Check	96	84	8	4	—	—	0.13
L17	Check	100	60	0	0	—	—	0.12
M16	Check	68	40	12	12	—	—	0.18
N15	Check	88	24	0	0	—	—	0.19
Laboratory Orchard, Summerland								
1D	Check	0	0	0	0	—	14.5	0.08
2D	Check	0	0	0	0	—	14.5	0.08
3D	Check	0	0	0	0	—	15.0	0.05
4D	Check	0	0	0	0	—	11.3	0.07

* DS—Drought spot.
CC—Corky core.

SUMMARY

1. The boron content of apple tissues and the soils in which the trees were growing was studied with particular reference to the occurrence of the physiological disorders, drought spot and corky core.

2. It is shown that low boron concentrations in the tree tissues can be correlated with high incidence of disease. In twigs from trees where the diseases were severe the boron content was generally below 10 p.p.m. In twigs from healthy trees the boron content did not usually fall below 14 p.p.m.

3. A correlation between low concentrations of boron in the soil and incidence of the disease was not established.

4. High soil concentrations, induced by treatment with either boric acid or borax, were associated with a general freedom from these diseases.

ACKNOWLEDGMENTS

Grateful acknowledgment is extended to Dr. H. R. McLarty who, as officer in charge of the investigations, gave valued assistance, and to Mr. J. C. Wilcox for supplying sample material and records from the experi-

mental orchard. I am also indebted to Mr. J. F. Hockey of Kentville, Mr. D. J. McLeod of Fredericton, Dr. J. G. Coulson of Macdonald College, and Mr. H. Wattam of Picton for their co-operation in forwarding samples from Nova Scotia, New Brunswick, Quebec, and Ontario.

TABLE 4.—A COMPARISON OF THE BORON CONTENT OF DISEASED AND HEALTHY TWIGS, LEAVES, AND FRUITS OF THE McINTOSH APPLE FROM VARIOUS PARTS OF CANADA

Source	Condition	Boron, p.p.m., dry weight		
		Twigs	Leaves	Fruit
Kelowna—British Columbia	Healthy	14.1	18.2	—
		11.8	10.8	9.6
		14.1	17.7	27.6
	Injected*	14.9	23.2	20.9
		14.3	17.4	12.5
		14.4	13.5	22.0
	Diseased	6 4	5.4	2.2
		9 3	4.8	3.2
		9.3	6.8	4.5
Summerland—British Columbia	Healthy	14 5	—	13.4
		14.5	—	13.2
		15.0	—	13.1
Vancouver—British Columbia	Diseased	7.3	—	—
Picton—Ontario	Diseased	—	—	5 8
Macdonald College—Quebec	Healthy	8 7	20.9	5.2
		12.2	24.0	12.6
		10.8	24 7	11.0
Oka Orchard—Quebec	Diseased	6.1	16.1	2.7
		5.9	12.1	2.5
		6.2	14.1	2.1
Fredericton—New Brunswick	Healthy	10.3	17.8	5.0
	Diseased	11.5	12.5	4.7
Kentville—Nova Scotia	Healthy	9.3	13.5	—
	Diseased	7.3	9.3	6.5

* These trees had been injected with various amounts of boric acid in 1934. Samples for analysis were collected in 1935.

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SCIENTIFIC AGRICULTURE

Vol. XVIII OCTOBER, 1937 No. 2

A STUDY OF THE FUNGOUS FLORA OF WHEAT ROOTS[1]

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Previous work conducted by the senior author and colleagues (15) and others has shown that the root system of wheat is rather extensive at the lower levels. The isolation of fungi from wheat roots growing in the surface soil layers and from the base of culms has been made by many investigators. The significance of some of the fungi obtained from such sources in causing rootrot of cereals is well known. The problem before us in the present work was to attempt a survey of the prevalence of fungi in or on wheat roots at the various soil levels; and, in so far as possible, to interpret their significance in reference to root diseases.

REVIEW OF LITERATURE

The literature on soil mycology in its many phases is extensive. In the present paper our literature review will be confined chiefly to investigations pertaining to the association of certain micro-organisms with plant roots. As roots of most plants are not by any means confined to the upper soil layers, the vertical distribution of fungi must be considered. Taylor (19) in making isolations from the soil obtained *Fusaria* from a depth of 24 inches. Rathbun (12) isolated various fungi from the soil to a depth of 44 inches. Both investigators attribute the distribution of soil fungi, in part at least, to the activity of grubs and earthworms. Starkey's (16, 17, 18) extensive experimental work and literature review brings forth abundant evidence to show that, as a general rule, soil microorganisms are most plentiful in the vicinity of plant roots. The abundance of fungi in material from the superficial layers of roots, as compared with soil material a short distance away, was striking. Fewer fungi were obtained by Le Clerg (10) from the lower soil levels than from the surface. Some species, however, were isolated from the 6-foot level. Further evidence that bacterial and mould activity is greater on or near plant roots was shown by the work of Thom and Humfeld (20); they observed that in either strongly acid or strongly alkaline soils, the roots, in this case corn, maintained a zone in their immediate vicinity with a reaction approximating neutrality. This area was consequently very favourable for microbial activity. Root material from tobacco plants attacked by rootrot

[1] Contribution No. 513 from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada. Read at the meetings of the Canadian Phytopathological Society held at Saskatoon, Sask., June 28, 29 and 30, 1937.

[2] Senior Plant Pathologist and Graduate Assistant respectively.

gave higher counts of micro-organisms than similar root material from uninfected plants. Fellows and Ficke (4) found *Ophiobolus graminis*, a wheat rootrot fungus, to occur at a depth of at least 15 inches. Greatest injury resulted when roots were infected in the upper levels near the seed. The investigations conducted by Bisby and co-workers (2, 3) reveal the common occurrence of fungi, including some parasitic forms, in the soils of Manitoba. Timonin (21) also working with Manitoba soils, reports that the number of fungi decreased at the lower depths of the soil profile. Anaerobic bacteria and fungi were more prevalent at the lower levels.

Pathologists working on root diseases have lately been giving some attention to fungi found within the roots, as well as to those forms obtained by isolation from root material or from the soil. The common occurrence of a mycorrhizal type of fungus in the roots of crop plants, particularly legumes, has been reported by Jones (8). The importance of direct examinations, to determine the number and kind of fungi in the roots, along with isolation studies have been stressed by pathologists working on root diseases of strawberry, raspberry and tobacco, namely Truscott (22), Hildebrand (6), Koch (9), Hildebrand and Koch (7) and Berkeley (1). The mycorrhizal type of endophyte was found to be a prevalent inhabitant of the roots of these plants. A new fungal parasite found in the roots of wheat grown in eastern Canada has recently been reported by Ledingham (11). Its pathogenic significance has not been fully determined.

MATERIALS AND METHODS

Wheat plants from which material was to be taken for isolation and examination were carefully excavated by the Weaver (23) method. The work was conducted in 1935 and 1936. Specimens were taken at Saskatoon and Indian Head, Saskatchewan, and included samples obtained during the seeding stage (June) and at a period just prior to maturity (August). The plants selected were growing under ordinary crop conditions. The roots were carefully traced so that definite material could be selected for each level. The following specimens were collected in each case:—*(a)* sub-crown internodes, *(b)* crown root pieces, and *(c)* seminal root pieces from near the seed, all of which were within the first six inches of soil; *(d)* pieces were then taken at the 1-foot level with additional samples at each foot to the depth of root penetration. As the roots were excavated, the proper pieces were selected as soon as they were exposed and placed in a clean envelope. No effort was made to take only portions bearing lesions and for the most part conspicuous lesions were absent below the first foot. Comparable specimens were taken at the same time and preserved for future study. If the samples to be used for isolation work had to be mailed, they were first allowed to dry, away from direct sunlight; otherwise they were plated the same day as collected. The specimens were rinsed in tap water, cut into suitable lengths and then washed thoroughly in sterile water (14). They were immediately transferred to potato dextrose agar plates after being washed and were incubated at room temperature.

The soil of the two locations mentioned were quite different. According to information obtained from Dr. J. Mitchell of the Soils Department, University of Saskatchewan, they may be briefly described as follows:

Saskatoon—"A dark brown, light loam soil of the Plains-Park transition zone. The profile has the dark brown soft cloddy surface, the brown long cloddy rather hard sub-surface, and the gray calcareous subsoil usual for the well-drained soils of this zone. The topography is undulating." *Indian Head*—"The surface soil consists of a very dark brown to black friable layer. The subsoil is more compact, somewhat columnar, underlain by a mixed brownish yellow and dark gray clay, cloddy in structure and high in lime. The topography is level to undulating."

ISOLATION STUDIES

The results covering the work for two seasons for each station have been combined. The number of isolates obtained from the roots of seedlings and mature plants were added to provide a total for each level. The combined data serve to emphasize the main objects of the work, which were to determine the species and relative abundance of fungi obtainable at the different levels. The total number of pieces for each level, from which isolations were attempted, approximate one hundred, except for the lowest depths where only a small amount of root tissue was available. The results are given in Table 1.

The tabulated results show the rather wide diversity of species. Considering total amounts, more fungi were isolated from the plant parts developing within the first foot of soil. There is a falling off, particularly after the second foot, but a fair number were isolated from the lowest depth of root penetration, namely four feet. Most of the species obtained from the lower levels were slow growing forms and it is possible that had they been present in material from higher levels, the fast growing species would have submerged them (Figure 1). On the other hand the rapidly growing fungi such as *Fusaria* were apparently not in or on the specimens from the lower depths. *Helminthosporium sativum* and *Fusaria* were the most abundant fungi isolated from the upper levels and only rarely were they obtained at or below the first foot. At the lower levels *Geomyces vulgaris*, *Botrytis terrestris*, *Botrytis* sp. and *Cylindrocarpon* sp. were rather common. Some other fungi such as *Colletotrichum* sp. and *Penicillium* sp. were present at most levels. Of the total number of isolates identified, roughly 40% were *Fusaria* and 10% *H. sativum*. Consequently well known wheat parasites or species with parasitic tendencies constituted around 50% of the isolates. Furthermore, *Colletotrichum* sp. which belongs to a genus containing forms parasitic on wheat accounts for another 7%. The next largest group include *Cylindrocarpon* sp. 6%. *Penicillium* sp. 6%, and *Geomyces vulgaris* 5%; the pathogenic significance of these, as far as cereals are concerned, is difficult to evaluate at present. The unidentified isolates account for about 13% of the total. The remainder contain some species which were found to be parasitic in laboratory tests. In addition isolations were made in 1935 from decayed root pieces, presumably old cereal roots, collected at the various levels. Generally speaking similar fungi were obtained from this material as from living roots. The following species isolated only from this source might be mentioned: *Fusarium sambucinum* Fkl. and *F. solani* (Mart) App. and Wr., from the first foot, and *Monotospora Daleae* Mason from the 2-foot layer.

TABLE 1.—FUNGI ISOLATED FROM THE SUB-CROWN INTERNODE AND ROOTS OF WHEAT PLANTS EXCAVATED AT SASKATOON AND INDIAN HEAD IN 1935 AND 1936

Fungi	Number of fungi from different levels															
	Saskatoon							Indian Head								Grand Total
	Sub-crown inter-node	Crown roots	Seminal roots				Total	Sub-crown inter-node	Crown roots	Seminal roots					Total	
			Near seed	1st foot	2nd foot	3rd foot				Near seed	1st foot	2nd foot	3rd foot	4th foot		
Mortierella elasson Sideris and Paxon			1	9			10		7	3					10	20
Mucor sp.			1	1			2				2	1			3	5
Zygorhynchus sp.		1					1									1
Acrostalagmus cinnabarinus Corda				2			2									2
Alternaria sp.								2			2			3	7	7
Botrytis terrestris Jensen				1			1				8	6	1		15	16
Botrytis sp												5			5	5
Cephalosporium curtipes Sacc.													1		1	1
Colletotrichum sp.	1	6	8		2		17	1	2	4	6	17	6		36	53
Coniothyrium sp.									2	1					3	3
Cladosporium herbarum (Pers.) Link.			3	3	1	1	8	1				1			2	10
Curvularia sp.	1				7		8	1	3	4		2			10	18
Cylindrocarpon magnusianum (Sacc.) Wr.												4			4	4
Cylindrocarpon sp.					5		5			1	10	15	12		38	43
Dicoccum sp.				1			1									1
Epicoccum nigrum Link.			3				3			6					6	9
E purpurascens Ehreub			1				1			1					1	2
Fusarium avenaceum (Fr.) Sacc.	2	4	5				11	1	21		1				23	34
F. concolor Reinking.											1				1	1
F. culmorum (W. G. Smith) Sacc.	2						2	2							2	4
F. equiseti (Corda) Sacc.	9	17	23	2			51	5	22	16	3				46	97
F. orthoceras App. and Wr.		1					1				4				4	5
F. oxysporum Schlecht.	1	5	8				14			2	1				3	17
F oxysporum var. *aurantiacum* (Link.) Wr.		8	16				24	4	30	13	7	1			55	79
F. scirpi var. *acuminatum* (Ell. and Ev.) Wr.	7	13	9	2			31	4		1					5	36
F. sporotrichioides Sherb.										1					1	1
Fusarium sp.	1				9		10		3	9					12	22

Geomyces vulgaris Traaen.				2			2		1	2	8	14	6	3	34	36
Gliocladium roseum (Link) Bainier	4		1	1			6									6
Helminthosporium sativum P.K. and B.	20	3	3	1			27	40	5	2					47	74
Hormodendrum cladosporioides (Fres.) Sacc.				1			1									1
Metarrhizium sp.			1				1									1
Monilia implicata Gil. and Abb.			1				1									1
Penicillium lilacinum Thom.				5			5				1	1			2	7
P. restrictum Gil. and Abb.			1				1									1
Penicillium (coremoid)			2				2									2
Penicillium sp.	12	2	5	2			21	4	2	7	3	2			18	39
Pestalozzia sp.				2			2				1				1	3
Stemphylium sp.										4					4	4
Torula allii (Harz.) Sacc.		6			1		7				2		9		11	18
Trichoderma koningi Oud.		2	1				3		1						1	4
T. lignorum (Tode) Harz.	1		1				2									2
Verticillium nubilum Pethybr.					1		1				4				4	5
V. terrestre (Link) Lindau				1			1									1
Undetermined		1	2	30	14	12	59	7	3	3	16	5	5	7	46	105
Totals	61	69	96	66	40	13	345	72	102	80	80	74	40	13	461	806

PATHOGENICITY TESTS

All the fungi reported herein were tested in a preliminary way. They were grown on a soil medium fortified with 1% corn meal and moistened with a weak dextrose solution. When growth was well established the medium was transferred to petri dishes; then twenty seeds thoroughly washed in sterile water were sown to each dish. After incubation at 24° C. for eight days, positive cases of root and coleoptile infections were very evident. Re-isolation was easily accomplished when desired. Wheat, oats and barley were used; the results are presented in Table 2. Fungi which gave negative reactions in this test were not listed.

TABLE 2.—INFECTIONS OBTAINED IN A LABORATORY TEST ON WHEAT OATS AND BARLEY SEEDLINGS WHEN INOCULATED WITH FUNGI ISOLATED FROM WHEAT ROOTS OR THE SUBCROWN INTERNODE

Fungus	Degree of infection on		
	Wheat	Oats	Barley
Fusarium orthoceras	Slight	Slight	Moderate
Fusarium culmorum	Severe	Severe	Severe
Fusarium avenaceum	Slight	Slight	Moderate
Fusarium oxysporum	Nil	Slight	Nil
Fusarium oxysporum var. *aurantiacum*	Nil	Slight	Nil
Fusarium sp.	Nil	Slight	Nil
Gliocladium roseum	Slight	Nil	Nil
Trichoderma koningi	Severe	Severe	Severe
Stemphylium sp.	Slight	Nil	Nil
Helminthosporium sativum	Severe	Slight	Severe
Cephalosporium curtipes	Severe	Severe	Severe
Colletotrichum sp.	Severe	—	—
Coniothyrium sp.	Severe	Slight	Slight
Pestalozzia sp.	Nil	Moderate	Moderate

It is of course realized that this was distinctly a laboratory test with conditions very favourable for the fungus. The plants did not develop beyond the very early seedling stage. The results show that fungi considered as major pathogens in causing common rootrot of cereals, such as *Fusarium culmorum*, and *H. sativum* were notably virulent. *Colletotrichum* sp. was classed as severe on wheat. Other species not so well known in root disease studies but which were virulent in this test, were *Cephalosporium curtipes* and *Trichoderma koningi.* Most of the fungi found to be parasitic were from the upper levels. The exceptions were *C. curtipes* isolated from the 3-foot depth and *Colletotrichum* sp. which was obtained from practically all levels. It is of interest to observe that none of the species were parasitic which were isolated frequently or almost entirely only from below the first foot.

HISTOLOGICAL OBSERVATIONS

When root pieces were collected for isolation purposes, some specimens from the various levels were preserved in formo-acetic-alcohol for later examination. This material was taken regardless of whether the roots at the respective level showed lesions or not. The samples in each case were of necessity small in number. A preliminary examination was made by

crushing the root pieces on a slide and staining with the usual lacto-phenol cotton-blue preparation. Some of the better preparations were destained by washing through ethyl alcohol, then re-stained with erythrosin and malachite green and mounted in balsam.

Observations showed that lesions visible to the naked eye were more common in the 1936 material than in the 1935 samples. Such lesions were always more conspicuous on the root pieces collected later in the season. Small discoloured areas, micro-lesions, chiefly in the cortex and observed only with the aid of a microscope, occurred in about the same frequency each year. These were also more common in the older specimens. Mycelium was invariably seen in roots showing either macro- or micro-lesions, while on the other hand mycelium was quite commonly found in roots which lacked distinct lesions. Some of the micro-lesions appeared to be of bacterial origin. The examinations revealed the presence of fungi associated with the roots at all depths including the 3-foot level which was the maximum depth at which specimens were collected. The subcrown internode and the crown roots near the surface frequently showed distinct lesions, along with the usual type of hyphae (probably *Helminthosporium sativum* and *Fusarium* sp.) associated with common rootrot infections. Very few lesions were seen below the first foot. The occurrence of mycelium in any great amount on the surface of the roots was rarely observed. Fragments of varying sizes of one or two types of dark mycelium were noticed rather commonly on the surface of roots at all levels, in the specimens collected both seasons. *Pythium* oospores of the browning rootrot fungus were seen in the Indian Head specimens, in slight amounts each year.

The direct examinations of specimens from the seminal root system revealed a phycomycete as the dominant fungus. This was in contrast to the prevalence of common rootrot fungi and their characteristic lesions on the crown roots and adjacent tissues. Common rootrot lesions were not found below the first 6 inches in the material examined whereas the phycomycetous type was not observed in the small sample of crown roots examined. In the seminal roots, however, this particular form of endophyte was observed at all levels. It was well established in some specimens, invading practically every cell of the cortex of some laterals for a considerable distance along the rootlet. There may have been more than one type but this could not be determined definitely. The mycelium was non-septate, rather large and well developed and ramified the cortical tissues passing from cell to cell without any distinct constriction in penetrating the walls. There was good evidence of appressoria in some of the epidermal cells indicating direct penetration. Moreover, the hyphae were commonly seen in root-hairs. The mycelium tended to mass in the inner cortical cells adjacent to the endodermis. It was not definitely observed beyond this barrier. In the cells where the mycelium collected in mass, the hyphae appeared to be surrounded with a granular material thus filling the entire cell. In some such cells the granular matter revealed traces of apparent old or empty hyphae (Figure 2). In a few cases, however, this formation upon closer examination seemed to be made up of fine hyphae, simulating somewhat the arbuscules depicted by certain

investigators studying mycorrhizal fungi in plant roots[3]. Although such infections, when well established, were very conspicuous yet there was no distinct tissue discoloration. The fungus was found in all collections of the seminal roots. The invasion was about the same in extent, for both the Saskatoon and Indian Head plants. The former grew on soil of average quality while the latter developed in soil of good fertility.

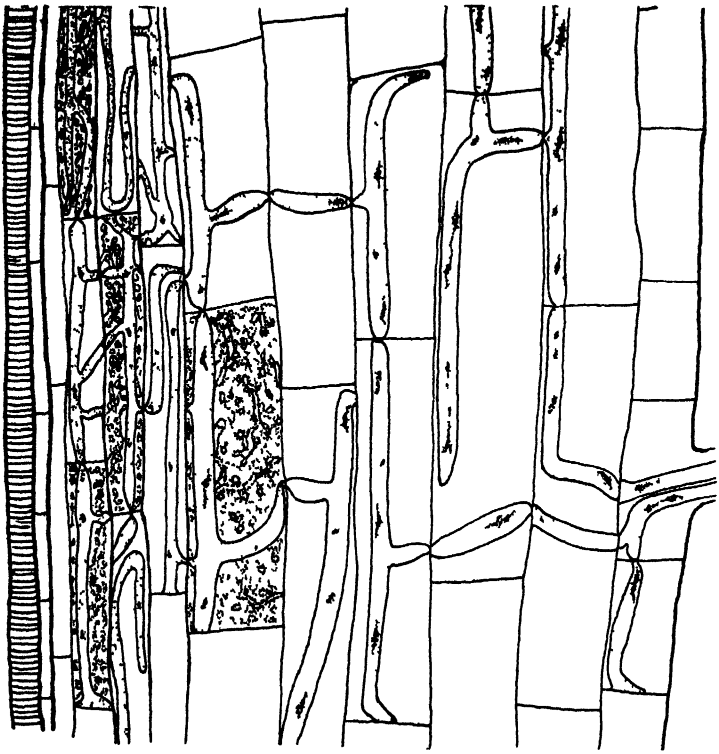

FIGURE 2. A composite drawing from specimens collected at Indian Head, showing an unidentified phycomycete well established in a portion of the cortex of a seminal root of wheat at the 2-foot level. The mycelium was inclined to mass towards the endodermis where cells filled with hyphae and granular material were observed Proportioned with the camera-lucida. ×250.

DISCUSSION

It has been shown in the present investigation that a large and diverse group of fungi can be isolated from wheat roots. It is realized, of course, that many phycomycetes and most basidiomycetes are not obtained by the usual methods. The direct examination of preserved material, therefore, was depended upon to reveal other fungi, especially root invaders, which would not ordinarily be obtained by isolation methods. In an effort

[3] NOTE.—Dr. L. W. Koch, who was present at the meeting and who has had considerable experience in examining tobacco and strawberry roots, kindly consented to go over some of our slides. He expressed the opinion that the phycomycete found in the wheat roots was very similar in appearance to the one commonly found in tobacco in Ontario. The massed granular material in the inner cortical cells were arbuscules according to Dr. Koch. Many of these were in various stages of disintegration.

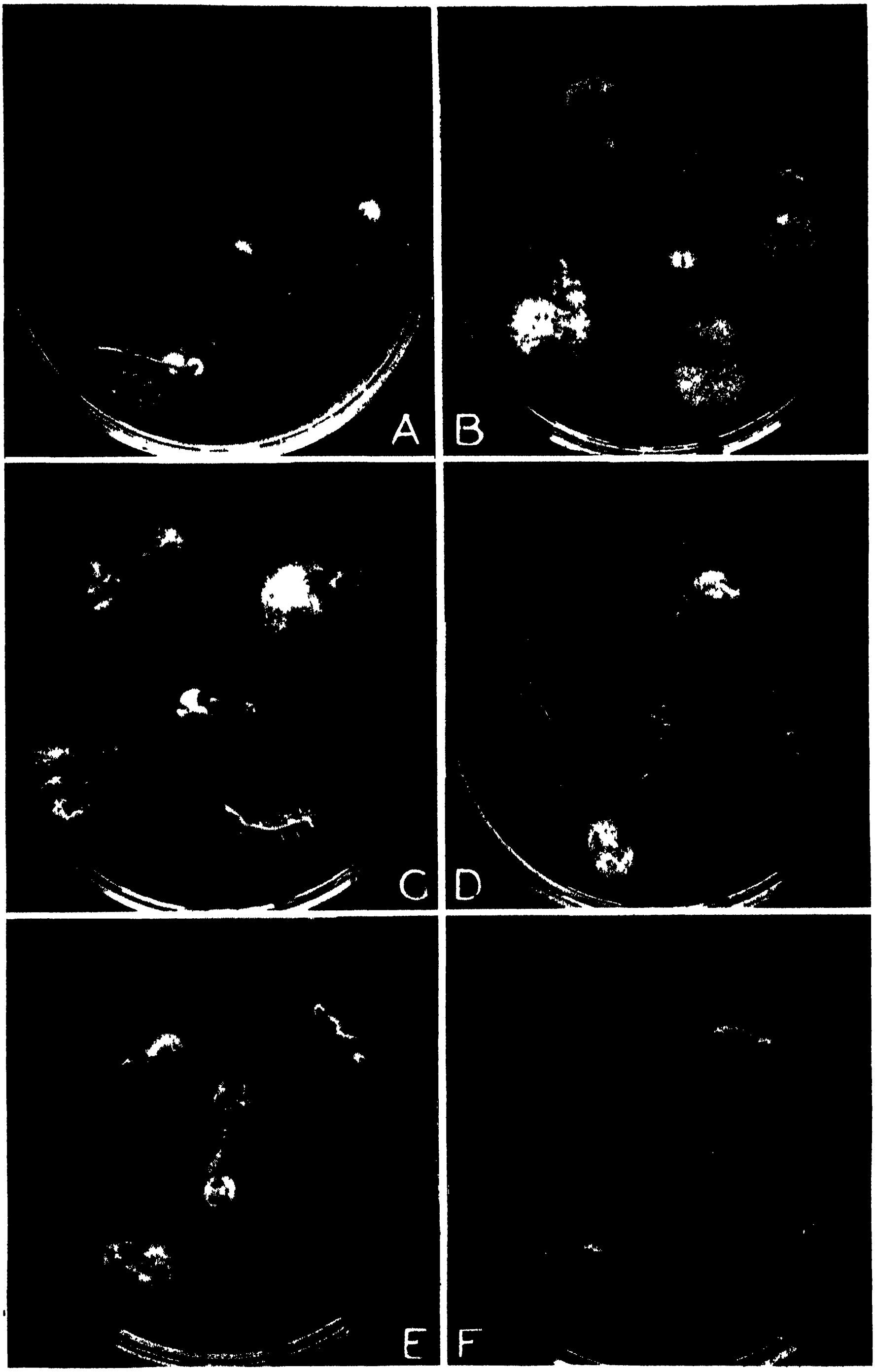

FIGURE 1. A representative group of plates showing the various fungi growing from the isolation pieces onto potato dextrose agar. (A) Subcrown internode, (B) Crown roots (C) Seminal roots near seed, (D) (E) and (F) Seminal roots at the first, second and third foot levels respectively. The specimens were collected from wheat plants excavated at Indian Head in August, 1936.

to eliminate as many of the distinctly soil forms as possible our isolation attempts were confined to root and subcrown internode material. The results from such isolations would then give a truer record of the fungi which invade or are associated in some way with the plant. It is this fraction of the soil flora which we assume may be of the greatest significance from a pathological viewpoint. The results of Henry (5) and Bisby (2) are of interest in this connection; they observed that *Helminthosporium sativum*, a well known wheat parasite, occurred rather infrequently in isolations from the soil. In the investigations under discussion, this pathogen was commonly isolated especially from the subcrown internode of wheat. Generally speaking, of the 44 identified fungi isolated, 15 or so can quite definitely be classed as pathogenes. On a basis of total isolates well over 50% belong to the pathogenic forms. These results indicate that a good proportion of parasitic isolates may be expected when isolations are made from plant tissues.

In regard to the vertical distribution, many isolates were obtained from the lower levels but very few were pathogenic. If this is the usual situation, it is of considerable interest, for a large part of the wheat root systems is found below the first 6 inches or first foot. In dry seasons especially, when the plant is largely dependent upon the seminal roots, invasions at the lower levels by such species as *Cephalosporium curtipes* or *Colletotrichum* might cause some injury. On the other hand, the common occurrence of pathogenic fungi in the surface layers as shown by isolations and lesions, is of definite significance. Within this upper zone, the main seminal roots meet at the first node and are connected with the crown by the subcrown internode. This portion of the axis must be considered of vital importance. A deep infection of the subcrown internode or proximal part of the seminal root system would certainly cut off the entire lower root system. Injuries of this nature have been observed in the case of infections by *Ophiobolus graminis* (15). Fellows and Ficke (4) found the same fungus to cause greatest injuries when inoculations were made at or near the seed. Furthermore the growth of crown roots and tiller buds takes place at the surface and within the upper soil layers. More isolates were obtained from the first foot than from below this level and most of these belonged to pathogenic species. Pathogenic fungi were, as a rule, rarely isolated from below the first foot. It would appear, therefore, that in problems of root diseases considerable attention must be given to infections of the plant parts found within the upper layers. It is not suggested, however, that the lower levels can be ignored, as information on infections at the lower depth is rather meagre. In dry season large and deep cracks appear in most prairie soils and these would allow easy access of surface organisms especially during heavy rains.

Direct examinations gave additional information on infections of the root system. The rare occurrence of lesions at the lower levels would appear to indicate lesser parasitic activity at these depths. On the other hand a phycomycetous infection was rather common below the first foot. This fungus was observed to be well established in portions of the cortex in roots of all orders. There were no ordinary pathological reactions at the infection foci, unless the granular cell contents mentioned above are considered as such. Discoloured cell walls or cell contents were not

observed. It is difficult to appraise the influence of such infections one way or the other. We are inclined to consider this endophyte as of the nature of a mycorrhiza somewhat similar to the type reported in papers reviewed above (8, 22, 6, 9, 7, 1).

SUMMARY

1. Isolations were made from the subcrown internode and roots of wheat plants excavated at Saskatoon and Indian Head in 1935 and 1936.

2. A total of 806 isolates representing 27 genera were studied. The results for the two years were totalled and tabulated to show the vertical distribution and frequency of occurrence of the isolates for each station.

3. More isolates were obtained from the first foot than from the lower levels, and over 50% of the total identified isolates were classed as pathogenic. Pathogenic fungi were rarely isolated from roots below the first foot. About 13% of the total number of isolates were undetermined.

4. Direct microscopic examination of preserved material revealed the rare occurrence of lesions on the roots below the first foot. A fungus considered as of a mycorrhizal type was commonly seen in many of the seminal root collections.

5. The pathologic significance of the results in studies of root diseases is briefly discussed.

ACKNOWLEDGMENTS

The authors wish to acknowledge with sincere thanks the help received from Dr. G. R. Bisby, formerly at the University of Manitoba, who identified most of the fungi, and also assistance from Dr. W. L. Gordon of the Dominion Rust Research Laboratory who determined the *Fusaria*. They wish also to acknowledge the assistance of Mr. B. J. Sallans who collected the Indian Head specimens.

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THE DEVELOPMENT OF A FLOTATION PROCESS FOR THE CLEANING OF CLOVER SEEDS

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[Received for publication, July 15, 1937]

FOREWORD

The problems of the seed cleaners were brought to our notice rather accidentally.

Mr. O. S. Hunter, of the A. S. Hunter Co., Durham, Ontario, came to us for material for an experiment he was making. In the course of conversation he told us much about difficulties in the separation of some kinds of seeds from others. Later, Mr. Hunter gave us considerable assistance by supplying information and material.

A few weeks later, Mr. A. W. Campbell, B.A.Sc., of the Eddy Seed Cleaners Ltd., came in to discuss the application to the mineral field of a centrifuge used in his business. In the natural exchange of ideas, we learned that the cleaning of seeds and their preparation for market was a considerable industry. We also heard more of the difficulties which existed in the removal from clover seed of some weed seeds for which there was no satisfactory process.

In the further pursuit of information on a problem that seemed to call for application of the principles of ore dressing, we called on the Hon. T. L. Kennedy, then Minister of Agriculture of the Province of Ontario. We discussed the problem with him in a general way and were referred to Mr. J. A. Carroll of the Markets Branch of the Department of Agriculture of Ontario.

Mr. Carroll told us the question of better grade seed was engaging the attention of the Seed Branch of the Dominion Department of Agriculture and consequently we met Mr. W. J. W. Lennox, District Inspector for Western Ontario of the Seed Branch of the Department of Agriculture of the Dominion of Canada. Mr. Lennox was intensely interested and offered to co-operate with us in any way possible, by giving information, supplying samples, analysing products, etc. We here acknowledge our indebtedness to Mr. Lennox and to Dr. C. W. Leggatt, Supervising Analyst of the Dominion Seeds Branch in Toronto. These gentlemen have given us every assistance, and in view of the considerable ignorance of two mining engineers about an agricultural problem, our work would have proceeded much more slowly without their co-operation.

Subsequently Mr. Lennox introduced us to Mr. Eddy of the Eddy Seed Cleaners Ltd., who opened up his plant for our inspection and study, and since then we have worked in close co-operation with Mr. Eddy.

The following report does not give a complete statement of the many experiments made but gives only summaries of them to indicate the nature of the experiments and the conclusions derived from them.

The investigation was carried on and is still progressing in the Laboratories of the Department of Mining Engineering, (provided through the instrumentality of the Hon. Chas. McCrea, then Minister of Mines) of the University of Toronto.

[1] Associate Professor of Mining Engineering.
[2] Consulting Engineer. At one time instructor in Mining Engineering.

The finances were partly supplied by the School of Engineering Research of the University of Toronto and partly by private contributions.

THE CLEANING OF SEEDS

The Seeds Act of the Dominion of Canada which governs the sale of crop seed in Canada divides seeds into various classes and subdivides each class into three grades and a reject. Dealers are not permitted to sell rejects for seed purposes, and the market for Grade 3 is limited. For each grade the Act specifies the allowable numbers of contained weed seeds.

The particular class of seed with which this investigation deals is that of alfalfa and the clovers, *i.e.*, sweet clover, red clover (Figures 1, 2 and 3), crimson clover, alsike and white clover (Figures 4 and 5).

For this class of seed, Canada (more particularly Ontario, Quebec and Alberta) has a large market both for export and for home consumption. This market might be much greater were it not for weed seeds. According to Mr. Lennox "the need for improved seed cleaning methods is apparent from the enormous loss annually sustained by agriculture in the province of Ontario through the prevalence of weeds in the fields and of weed seeds in the grain and seed produced and used for seeding in the Province. Depreciation in market value of the seed crops because of weed seeds and other impurities which cannot now be removed probably amounts to between $200,000 and $300,000 each year. The annual production of alsike clover seed in Ontario averages more than 100,000 bushels and it is a conservative estimate that the crop is depreciated in value on an average of at least $1.00 per bushel because of weed seeds that cannot be removed effectively. Alfalfa and sweet clover seed production varies widely and averages 80,000 bushels per annum and much of the value of this is lessened because of such weed seeds as bladder campion and couch grass. Red clover seed production has decreased greatly within the Province, partly because it is impossible to clean a large proportion of the crop so that it will be marketable." . . . .

"The direct loss in depreciation of seed crops is only a part and a small part of the loss to agriculture sustained through weed seeds in seed crops. The standards under which seeds of the various grades may be sown under the Dominion Seeds Act are probably as high as it is now practicable to enforce; but there is wide distribution of weed seeds in clover seed sold in commerce, and this cannot be avoided unless and until improved means are found for cleaning seeds. Besides the seed sold within the law, which may contain noxious weed seeds, there is a considerable portion of the clover seed crop so badly contaminated with weed seeds that it is unmarketable to the regular seed trade and is a serious menace as a potential seed supply in the districts where grown."

By the Seeds Act of Canada, weed seeds are divided for each class of crop seed into four groups:

1. Prohibited noxious[1]
2. Primary noxious
3. Secondary noxious
4. Other weed seeds

according to the damage they do to the crops.

[1] Excellent coloured illustrations of the various weeds may be found in *Farm Weeds*, published by the Department of Agriculture, Ottawa.

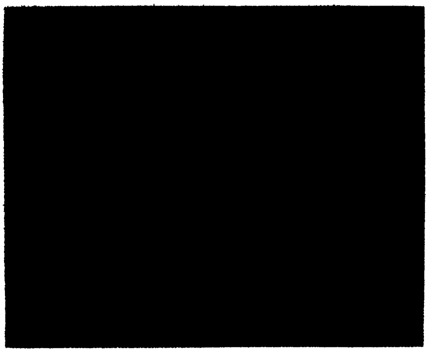

FIGURE 1. Alfalfa seed. Natural size $\frac{1}{10}$ inch approx.

FIGURE 2. Sweet clover seed. Natural size $\frac{1}{10}$ inch approx.

FIGURE 3. Red clover seed. Natural size $\frac{1}{10}$ inch approx.

FIGURE 4. Alsike clover seed. Natural size $\frac{1}{10}$ inch approx.

FIGURE 5. White clover seed. Natural size $\frac{1}{10}$ inch approx.

FIGURE 6. Bladder campion seed. Natural size $\frac{1}{10}$ inch approx.

FIGURE 7. White cockle seed. Natural size $\frac{1}{20}$ inch approx.

FIGURE 8. Nightflowering catchfly seed. Natural size $\frac{1}{20}$ inch approx.

For the seeds of alfalfa and clovers the prohibited noxious weed seeds include

Dodder (*Cuscuta* Spp.)

and five others.

Primary noxious weed seeds include

Bladder Campion (*Silene latifolia*)
White Cockle (*Lynchnis alba*)

and nine others.

Secondary noxious weeds include

Nightflowering Catchfly (*Silene noctiflora*)
Ribgrass (*Plantaga lanceolata*)
Field Pepper Grass (*Lepidium campestre*)

and 20 others.

The group of "other weed seeds" comprises all other species which are not in the above three classes nor are crop seeds and some of which, such as lamb's quarters and foxtail are difficult to remove from clover seed.

The seeds of bladder campion, white cockle and nightflowering catchfly are so much alike that it requires an expert to distinguish between them. (Figures 6, 7 and 8.)

The standard methods of separation from clover seed of the weed seeds named above leave much to be desired. The treatment of the campion-catchfly-cockle group of seeds is so difficult that no satisfactory method of separation was known, so that this group was selected for first attention. The difficulty in separating these seeds from the clover seeds arises from the fact that the weed seeds and the clover seeds are alike in being practically of the same size, the same shape, and the same specific gravity.

So many attempts have been made and have failed to give the desired separation it may be well to state how close the separation must be before the clover seed may be graded under the Seeds Act[2].

The Dominion Seeds Act specifies that for the clovers to make No. 1 grade there must be no prohibited noxious nor primary noxious weed

[2] The Seeds Act. Acts, Orders and Regulations No. 24, Published by the Department of Agriculture, Ottawa, Canada.

seed and not over five secondary noxious weed seeds per ounce in red clover seed, sweet clover seed, and alfalfa seed and not over ten per ounce for alsike and white clover seed.

In sweet clover, red clover and alfalfa seed there are from 15,000 to 20,000 seeds per ounce; in alsike about 40,000 seeds per ounce. In rejected seed there may be from a few to many thousands of these noxious weed seeds per ounce and yet the extraction of these weed seeds must be so good that the remaining clover seed must be entirely free from prohibited and primary noxious weed seed to be Grade No. 1 and within 1/40 of 1% of freedom from secondary noxious weed seeds to make the same grade. This degree of separation is away beyond any ordinary separation of metallurgical products. This high degree of purity must be obtained without a serious loss of good seed, otherwise the economic value of any separation would be lost.

To complicate matters still further it must be recognized that materials to be treated are living seeds that have to be used by farmers and that, therefore, nothing must be done to spoil or lessen the germination of the seed, and further, the seed must not have a sticky feel nor a bad colour, or the farmers will not want to buy it. Also, nothing poisonous nor bad-tasting nor bad smelling can be used in making the separation.

SAMPLING AND ASSAYING

Early in the investigation it was found necessary to have a quantitative measure of the degree of separation of the weed seeds from the clover seeds. A quantitative measure involves sampling and subsequent analysis. The nature of the seeds precludes any method of analysis except visual examination and detailed counting of the weed seeds in a weighed quantity of clover seed. Commonly a ¼ oz. sample is used, but sometimes it is necessary to examine a much larger quantity. To us this counting of the seeds becomes very tedious, particularly so because each seed must be seen through a glass magnifiying 5 to 10 diameters to make identification easy, though professional analysts are able to do the counting and identification without magnification.

To assist in passing the seed under the magnifier, a small picking belt, hand driven was constructed. A small hopper to hold 2 or 3 ounces delivers to a belt through an adjustable gate a stream of seed 4 or 5 seeds wide and 1 seed deep. Supported on a post by a hinge is a large size "linen counter" magnifying glass. By means of a needle in a wooden handle, individual seeds can be flicked off the belt into a hopper for examination. Otherwise, the seed stream delivers into a small bin at the end of the belt, and the required seeds counted as they pass under the glass and the number recorded by tripping a Veeder Counter for each seed.

A photograph of an early form of the picking belt is shown in Figure 9. Occasionally samples were sent to Dr. Leggatt[3] for an official count and for identification of individual seeds. Although this picking belt speeded up the analysis and removed some of the drudgery, the tendency is still to cut down the size of the sample to be analysed. It is not advisable to make the sample any less than ¼ of an ounce. With this quantity, the errors

[3] See Foreword.

may be great, due to the difficulties of sampling. In counts that come near the border line of the various grades, it may be necessary to count several ounces. For sampling the seeds, a small Jones sampler was used by passing a small stream of seeds over the partitions of the sampler. No better method of sampling is known.

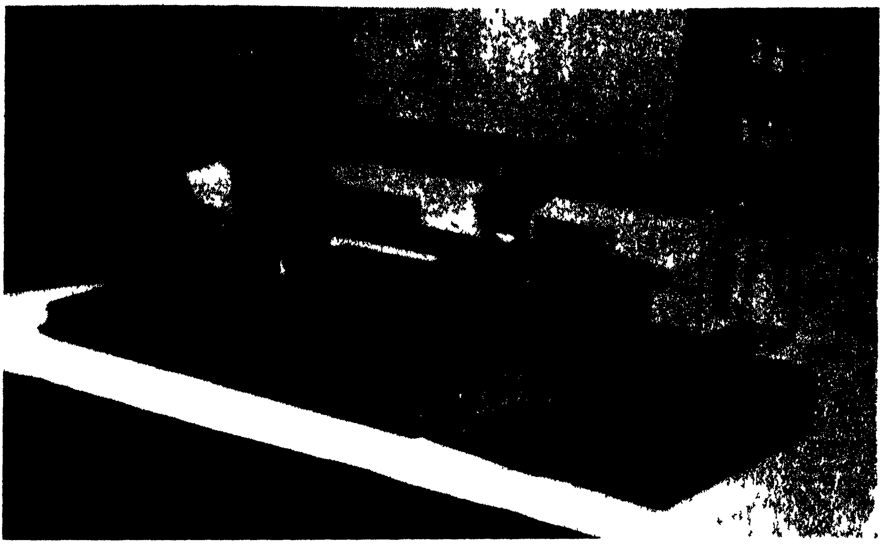

FIGURE 9. Counting belt.

As an illustration of the difficulty of sampling, consider these figures. A lot of sweet clover seed containing catchfly seed was divided by the sampler into 8 parts of $\frac{1}{8}$ ounce each and each part analysed with these results:

2 4 1 3 5 4 2 3 weed seeds.

Per ounce this is:

16 32 8 24 40 32 16 24 weed seeds,

an average of 24 weed seeds per ounce. A count of another ounce gave 22 per ounce. These figures show a standard deviation from the mean of 21.6%, and the resulting grade might have been No. 2, No. 3, or rejects, depending on which small lot had been taken for analysis.

Suppose it is stipulated that the tolerance in assay shall not be more than $\pm 10\%$ and that the degree of certainty shall be 80%, that is, the error will not be greater than 10% in 4 assays out of 5. Reference to tables of probabilities, such as, Tables II and III in Pearson's Tables for Statisticians, Part 1, shows that, with as many as 30 noxious weed seeds in the sample, to ensure that the certainty be 80%, it would be necessary to allow a count of 25 to 35, a tolerance of over 16%, much greater than the stipulated error. If the sample, even with this degree of error, was on the border-line between grade 2 and grade 3, that is, with 5 primary noxious weed seeds per ounce, it would be necessary, in order to come

within the permissible tolerance, to count about 6 ounces of seed, much too large a quantity.

With this grade of seed, and to ensure a degree of certainty of 4 times out of 5 on a count of 2 ounces, it would be necessary to allow the count to be between 7 and 14, a tolerance of 35%. With one-ounce samples, which are customarily the largest used, either the degree of certainty would have to be reduced or the tolerance increased.

In drawing conclusions from our assays this difficulty in sampling has been kept in mind, and before reliance was placed on differences in results of comparative tests the assays were scrutinized to see if the differences lay within the probable sampling error.

A further discussion of the sampling errors in seed analysis may be found in *The application of statistical methods to seed testing*, by G. N. Collin published as Circular No. 79, by the United States Department of Agriculture, Washington, D.C.

STANDARD METHODS

The standard methods of cleaning seed take advantage of differences in the size, shape, or specific gravity of the seeds. When any differences are present in any appreciable degree, simple and obvious methods may be used. The difficulty comes when the seeds to be separated approach each other closely in all of these characteristics. The natural procedure in a case of this kind where separations are difficult is first to test the usual methods of separation under delicate adjustment.

The literature dealing with the cleaning of clover seed is scanty. It seems that most seed cleaners are reticent on any development they may have made on the obvious processes. We found nothing that would suggest other than that the art was restricted to screening, air classification, water classification, with occasional use of heavy solutions, gravity separations on tables, and a few special processes to take advantage of outstanding differences in surface.

Gravity Separation on Oscillating Tables

The Sutton-Steel and Steel pneumatic table is used to some extent in seed cleaning plants but fails to separate the campion-cockle group of seeds from the clover. Repeated attempts with an ordinary Wilfley table also gave no results.

Hydraulic Classification

Separation of the campion-catchfly-cockle seeds from the clover seeds by rising currents of water is unsatisfactory.

The specific gravity of the seeds being about 1.2, there is very little sinking power in the seeds to begin with, so that vertical eddy currents in the water must be kept at a minimum. Further, the seeds are so much alike that even with closely sized seeds there is very little possible margin of difference in the densities of the seeds on which to work. Under the most carefully controlled conditions in a tubular classifier the separations obtained were never good. In the classifier used for testing purposes the effect of vertical eddies was reduced to a minimum by introducing a swirling motion to the water. A stirring device was added to the feed tube of the classifier to ensure that air bubbles were eliminated and also to overcome

the tendency of the seeds to agglomerate. By these means, the seeds were each given a chance to rise or sink individually and solely, according to their specific gravity.

In no sample of clover seed tested by this method was it found possible to produce a clean clover seed free from catchfly. In a few cases it was found, however, that by closely sizing the seed by screening before submitting it to classification, a lighter product could be obtained consisting almost entirely of catchfly seed, but the remaining clover seed was not catchfly-free. Later, this result, although it did not give the desired separation, was found to be important as an auxiliary to other processes. The diagram shows the arrangement of the classifier. (Figure 10).

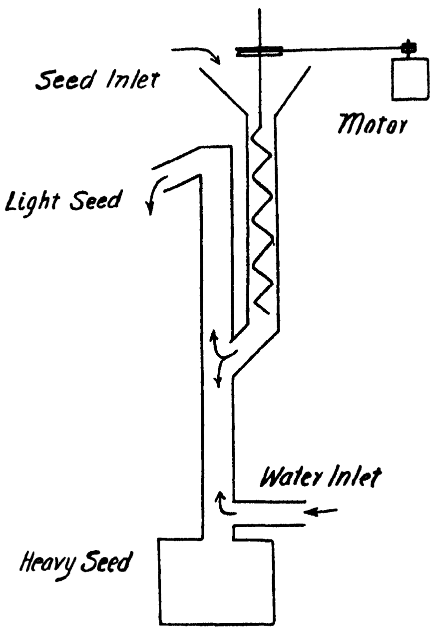

FIGURE 10.

The substitution of a current of air for the rising water currents was unsuccessful.

Sink and Float Tests and Centrifuging

"Sink and float" tests in salt solutions failed to make a separation. Eddy Seed Cleaners Ltd. report that salt solutions, even when reinforced by centrifugal action, only make a partial separation of the cockle group. The Eddy Company report was confirmed by small scale tests with a Babcock centrifugal cream tester.

None of the usual processes providing satisfactory separations even under the best of conditions, it became necessary to consider some unusual processes.

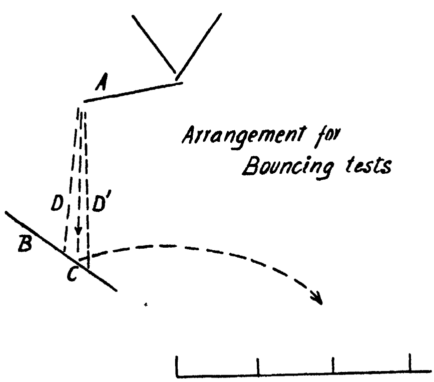

FIGURE 11.

Resiliency Tests

Remembering that sound cranberries can be separated from soft ones by making them bounce, trials were made to determine if this method could be applied to the seeds under investigation.

A simple piece of apparatus was set up (Figure 11) and the seeds allowed to fall from the edge of a feed chute (a) on to a glass plate (b) inclined at 45°. As seeds bounced from the plate they were caught in a series of parallel sample troughs. For the results of this

experiment to be definite, the seeds should fall along a simple line (c). It was found, however, that due, not only to small differences in size but also to the fact that a seed might pass over the edge on either its longer or shorter diameter, the seed would spread out and fall anywhere within the lines (d d′), and so the results were indeterminate.

The glass bouncing plate was replaced with a steel rule 1/16″ thick. Only the seed that bounced from this narrow edge was considered. The results were not promising and the experiments were discontinued. The differences in bounce of seeds of the same kind, depending on how they struck the plate, were great enough to mask the difference in bounce of two different kinds of seed.

Mushing Tests

It was discovered accidentally by leaving seeds under water over the noon hour that, when clover seed and catchfly seed were soaked in water, in the course of time, both absorbed water and became soft. The time required for the seed to soften varied with different lots of seed, and in the earlier samples tested the catchfly seed softened before the clover seed, or most of it did. It seemed from this that a time of soaking might be found which would soften the catchfly seed to a point where a fairly stiff brush would flatten out or mush the weed seed without damaging the clover seed. If this could be done, then a separation could be made by screening.

A number of experiments were made along these lines but the results were not satisfactory. The difference in the behaviour of various samples was very great. In some cases the weed seed softened first and in others the clover seed. Even in those cases where the weed seed did soften first some of the clover seed softened also, and some catchfly seed remained very hard. In any case the long soaking and subsequent expensive drying would only have been justified by a complete separation, of which this scheme gave no promise. The experiments were discontinued in spite of one case where a complete separation was effected.

Similar experiments were made by soaking the seed with various strengths of dilute hydrochloric acid and also of dilute caustic soda. There was no appreciable difference in results from those obtained with water except that many of the catchfly seeds turned red with the acid and the immature seeds seemed to soften a little faster than the mature seeds.

Differential Absorption

When clover seeds or weed seeds are wetted and allowed to dry slowly they will absorb the surface water and swell slightly. The amount of swelling will vary with the different seeds and with different lots of the same seed, and is probably a function of the amount of water absorbed. When the flotation process or the wet centrifugal process is used the time of contact with water is very short and since all excess water is promptly removed this swelling is very slight and the total moisture is well within what would damage the seed.

It has been observed that when just the correct amount of water was left with the seed in most cases a considerable proportion of the catchfly seed swelled more than did the clover seed after the seed had been in the bag for a day or two. This made it possible to separate some of the catchfly by screening provided the seed had been carefully sized in the first instance.

This method of separation did not give similar results with different lots of seed nor did it give the high percentage of separation required. Also it must be used with great exactness as too little water will not give the required swelling and too much may cause the clover seed to swell more than the catchfly seed, and also may cause the seed to become musty or to heat.

Air Friction Tests

There is considerable difference in the surface of the catchfly seed and the clover seed. The clover seed is smooth while the catchfly seed is "pimply" (Figure 8). It seemed possible that this difference might cause the seeds to be deflected differently if they fell freely into a very thin, horizontal, high velocity air jet. With very closely sized seed the pimply surfaced seed might be expected to gather horizontal speed due to air friction more quickly than would the smooth clover seed.

This was tried with a small orifice about 2 inches long and $\frac{1}{32}$-inch wide with $2\frac{1}{2}$ lbs. air pressure. The seeds were allowed to fall independently across this stream of air close to the orifice and were caught in a series of parallel sample troughs. The experiments were not conclusive.

The orifice was narrowed to 1/100 of an inch and the air pressure raised to 7 lbs. per sq. inch. The seed used was sweet clover containing much nightflowering catchfly seed. The resulting seed scatter was divided into three parts and analysed. For 10 gram lots the counts were: for the lot nearest to the orifice, 46 catchfly seeds; for the middle one, 54 catchfly seeds; and for the portion that was blown the farthest, 54 catchfly seeds. Although this difference is not more than a possible sampling error, it seemed to indicate that a higher air pressure might give better results and the air pressure was raised to 11 lbs. per sq. inch. This was sufficient to blow some of the seed 15 feet before it fell to the ground. The seed scatter was divided into 5 equal parts according to distance of travel, and analysed for weed seeds, giving the following counts:

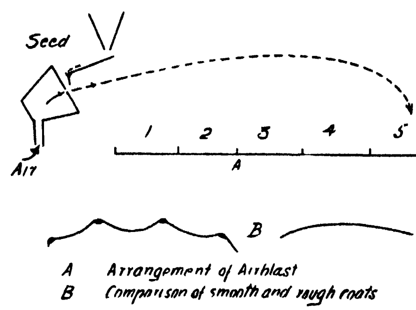

FIGURE 12.

Distance of travel in yards	1	2	3	4	5
Catchfly seeds per 10 grams	37	49	49	54	57

Although these results appear to justify the original assumption, there is no indication of any probability that a process of separation might be developed by this means to give the completeness of separation desired. Projecting the seed into the air from the pulley end of a fast moving belt gave similar incomplete separations.

Separation by Colour Differences

The recent great improvements in photo-electric cells have made separations possible by using "electric eyes" that were not thought of a few years ago. It is certain that a good degree of separation could be made of the campion-catchfly-cockle family of weed seeds from the clovers. It is desirable for a commercial machine to handle at least 4 bushels per hour. Since each seed must be examined individually and assuming that each electric eye can sort at the rate of 20 seeds per second, this would mean a machine containing over 500 electric eyes each with its accessory equipment. Such a machine, though possible, would be too costly.

Secondly, it is doubtful whether such a machine would operate to give the completeness of separation desired. Catchfly seed, which ranges in colour from black through brown to red, can be separated from sweet clover seed, which is yellow; but in the case of alsike clover, which contains a large proportion of very dark green seeds, a different set of "eyes" would be required, adjusted to shades of brown. We think the natural differences in colour of the same seed will prevent perfect separation.

Because of these colour variations and the high first cost of the machine required, we did not make any experiments to test the actual degree of separation possible. We do not consider this means of separation is practicable at present.

Electrostatic Separation

In testing this method a small electrostatic machine, giving between 30,000 and 40,000 volts was used. The materials tested were seeds air dried for several days, seeds stove dried, and seeds that were slightly moistened and then air dried until all surface moisture had evaporated. The seeds consisted of sweet clover with 50% bladder campion, sweet clover with 10% nightflowering catchfly, and alsike containing nightflowering catchfly. In no instance was there any noticeable separation. We do not think that for clover seeds this method holds any promise.

Magnetic Separation

The separation of one material from another by coating some of the particles with a magnetic substance and then removing the more heavily coated ones with an electro-magnet has in some cases been successful. This scheme was tried with sweet clover seed containing catchfly seed. The catchfly seed being rougher than the clover seed might be expected to hold more magnetic material than the smoother seed. High grade magnetite was ground until dusty in a ball mill and then mixed with the seed. The amounts of magnetite used varied from 1% to 7% of the weight of seed. The material was rolled in a bottle until every seed has a chance to become thoroughly coated. The coated seeds were passed through a Wetherill Magnetic Separator with a ¼ inch gap and amperages ranging from 1½ to 15 amps.

The percentage of catchfly seed removed increased with increase of magnet strength but so did the amount of clover seed lifted (Table 1).

It was only with high amperage that an approximation to the desired removal of catchfly seed was obtained, and that at the cost of the loss of one-third of the original weight of good seed. Further, the good seed remaining was badly blackened with the magnetite, which was difficult

to remove even by washing with water. This dark seed is not marketable.

We have since learned of a process which uses magnetic separation after treating the seed with a magnetic material. The process is reported as being useful for some seeds, but does not appear to be in general use.

TABLE 1

Amperes	Portion lifted		Remainder
	Weight	Assay	Assay
	%	N.F.C.	per oz
1¼	4 4	70	104
4¼	14 7	50	24
8¼	22 7	30	56
15	34 9	25	8

Flotation

Up to this stage no process tried had given any promise of success except possibly some form of vanning machine and even that did not hold out any great hope of success. Every other likely process had been tried except flotation, and without any expectation of success flotation experiments were made, and according to expectation they failed.

Both types of modern flotation machines were used in laboratory sizes. One type provides a voluminous, brittle froth, of large bubbles, with minimum agitation. The other type gives a comparatively small volume of a stiff froth, with small bubbles, and uses violent agitation.

Frothing agents used were pine oil, alcohols, soaps, "Snap", and an extract from the weed seeds themselves which has considerable frothing properties.

Collecting agents tried were linseed oil and some other organic oils, coal oil and other petroleum products.

The circuit was either acid with hydrochloric acid or made alkaline with lime, caustic soda or sodium silicate.

It can be readily realized that the choice of possible reagents is very limited because of the organic nature of the seeds and the subsequent use to which they must be put. Further, except in a most vague way, nothing is known of the character or surface composition of the seeds which might be a guide to the selection of reagents. Consequently every experiment was a pure and simple "shot in the dark". Later when more was known of the differences of seed coatings these flotation experiments were repeated and others made. The results were consistent failures in obtaining even a fair approach to a separation.

The reasons for the failure appear to be:

(1) A very small difference in wettability of the various seeds.
(2) Failure to find a suitable harmless reagent to increase this difference in wettability.
(3) The turbulence inherent in modern frothing flotation machines to a large extent prevents the attachment of bubbles to the seeds.
(4) The seeds have such a low specific gravity, so little greater than water, that they have a very small sinking power and are consequently mechanically trapped in the froth.

It is not impossible that with increasing knowledge a froth process might be modified to suit these seeds but at present the use of modern commercial flotation machines is not possible.

DEVELOPMENT OF A FLOTATION PROCESS

All the previously described experiments having proved unsuccessful, the only other way to attack the problem of the separation of clover seed from the catchfly group of seeds appeared to be to find some unknown property of one of or both the seeds that might lend itself to the object in view.

Nothing had been found in the literature that offered any lead, so a more or less random series of experiments were undertaken. One series consisted of soaking the seeds in any liquid that came to hand and watching the results under the microscope.

Having been divested of any pre-conceived notions and prejudices, no liquid that came handy was passed by without a trial; the liquids ranging from distilled water to Bass' Pale Ale and chloroform. There were no conspicuously unusual results. It so happened that one lunch hour some mixed seed had been left in water on the stage of the microscope and before an open window. During the rest period some of the water evaporated and left the seeds sticking up out of the water like islands, and dust that had blown in with the wind had settled on the water. This was nothing unusual, but what was new was that the floating dust accumulated around one kind of seed in preference to another. Because of those few specks of dust an investigation that was almost dead came to life. That dust showed there was a difference in the curvature of the water surface around the different seeds, therefore there was a difference of surface tension; therefore some kinds of seeds must be more wettable than other kinds, and therefore the flotation process, being dependent on differences of surface tension, ought to work as a means of making a separation of the various weed and other seeds. It had not worked when tried previously. Was the evidence of the dust a delusion? A resort to the soda water bottle would soon tell. Some sweet clover and catchfly seeds were sprinkled on the bottom of a beaker and covered with water. They all stayed on bottom. A squirt from the syphon introduced bubbles. When the first fizzing was over the remaining gas precipitated on the glass of the beaker and on some of the seeds. In a few minutes all of the clover seed had been raised by the bubbles to the surface of the water along with a few catchfly seeds, but most of the weed seeds remained at the bottom. Flotation as a means of separating clover seed from catchfly seed is a possibility in spite of the evidence from previous failures.

The previous experiments with modern flotation machines were repeated. Changes in method of operation, such as feeding the seed to the froth instead of to the pulp, and other variations were tried but the conclusions arrived at and stated previously were confirmed.

An approximate comparative measure of the wettability of some of the seeds was obtained by placing a number of each seed on blotting paper and then placing the paper on water. The paper soon became waterlogged and sank, leaving all the seed floating. This floating was not because the seeds were lighter than water for the specific gravity of all these seeds lies between 1.2 and 1.4. Each day the number of seeds that had sunk was counted (Table 2).

These numbers do not show any very marked differences except in the case of white cockle, which is distinctly more wettable than the others.

TABLE 2.—PERCENTAGE OF SEEDS THAT HAD SUNK AT THE END OF EACH DAY

No. of days	Bladder campion	Night f. catchfly	White cockle	Alfalfa	Alsike clover	Sweet clover
1st	0	1	10	0	0	0
2nd	1	3	10	1	0	0
3rd	3	4	39	1	0 S	0 S
4th	3	4	40	50	60	40 S
5th	3 S	4 S	42 S	95 S	90	95 S
6th	5 S	4 S	55 S			

S—Means that the floating seeds had begun to sprout.

All these seeds must have a water resistant skin, otherwise they would have absorbed water and sunk. The three clovers show a slightly greater resistance to wetting than do the three weed seeds. These figures cannot be used as absolute measures of the degree of wettability of the various seeds for the seeds absorb water in varying degrees and each kind of seed varies considerably in itself from one lot to another, but they do show that the bladder campion group of seeds has outside coats that are more easily wetted than the outside coats of the Clover group of seeds.

A method more susceptible to adjustment than the modern flotation processes was required. The film flotation process seemed to be the most promising, and this method was developed finally into a commercial means of freeing clover seed from the seed of bladder campion, nightflowering catchfly and white cockle. Subsequently greater knowledge added dodder and others to this list.

Preliminary trials were made on a test tube scale. These trials developed into a standard routine method for testing the feasibility of proposed working conditions which later could be tried on a larger scale. A measured quantity of seed, about a third of a test tube full, is placed in a tube and water or other liquid added till the test tube is half full. It is then shaken by hand for a period of ½ minute. The seeds are dumped onto a piece of 30 mesh wire cloth, and spread by the finger to a layer one seed deep. The bottom of the screen is then wiped with a towel to remove excess moisture and the seed allowed to dry for one minute. The piece of screen at an angle of 15° from the horizontal is then introduced edgewise into a basin of still water, allowing some seeds to sink and to be removed with the screen. The floating seeds are gathered by pouring the water onto another piece of screen. The two lots of seed are then washed through a funnel into a long narrow graduated glass tube closed at the bottom by another piece of screen onto which the seeds are finally washed for drying or immediate counting. The relative quantities are read from the graduated tube. Although this method cannot give very precise results, it is very useful for comparative tests and is a great time and labour saver when hundreds of tests are required.

The fundamental principle of this method is: (1) to wet thoroughly all the seeds; (2) expose the wetted seed to air so that some of the seeds may dry more quickly than others; (3) present the seeds individually to the surface of a water bath; (4) the seeds which have dried will float on the water by surface tension while the seeds that are still wet will sink.

Among the many factors which affect the operation of this method, the principle ones are: (1) the nature of the seed coat; (2) the thoroughness of the wetting; (3) the presence of substances which help or hinder the wetting; (4) the degree of agitation while wetting; (5) the time allowed for wetting; (6) the time allowed for drying; (7) the speed at which the seeds reach the surface of the water bath; (8) the angle of entry to the water; (9) the surface tension of the water; and (10) the temperature of the water.

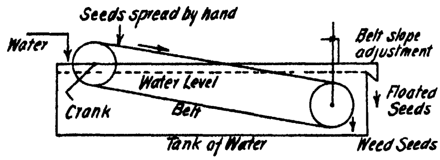

FIGURE 13.

The first machine used to test the operation of this method on seeds was simply a piece of rubber belting travelling around two rollers and dipping into a tub of water (Figure 13). This device developed into a continuous operating machine with a rubber belt 12 inches wide dipping twice into water and provided with a stirrer to mix the seed water and oils, etc., with feeding and measuring devices, etc. (Figure 14). A canvas belt was tried on this machine and discarded. The rubber belt was not satisfactory, partly on account of the interference of waves washing up on the belt, and on account of the difficulty of removing the water during the drying period.

The next machine used a wire cloth belt around three rollers (Figure 15) and gave such promising results that a larger experimental machine

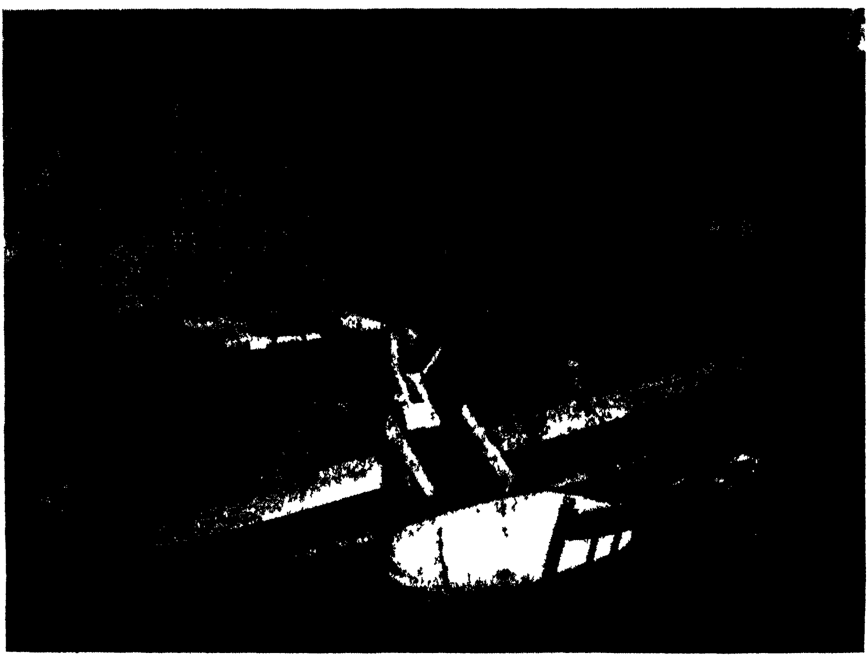

FIGURE 14

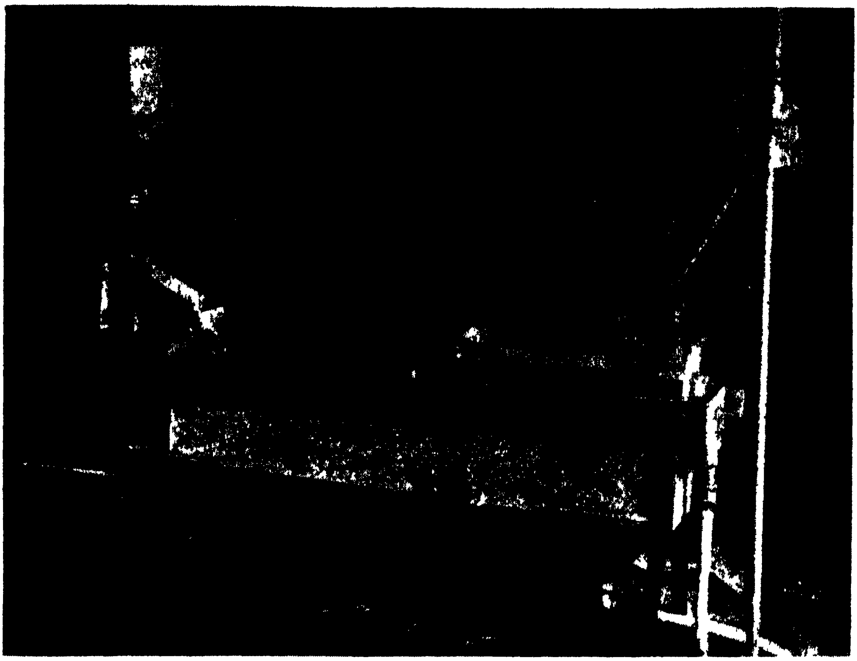

FIGURE 15.

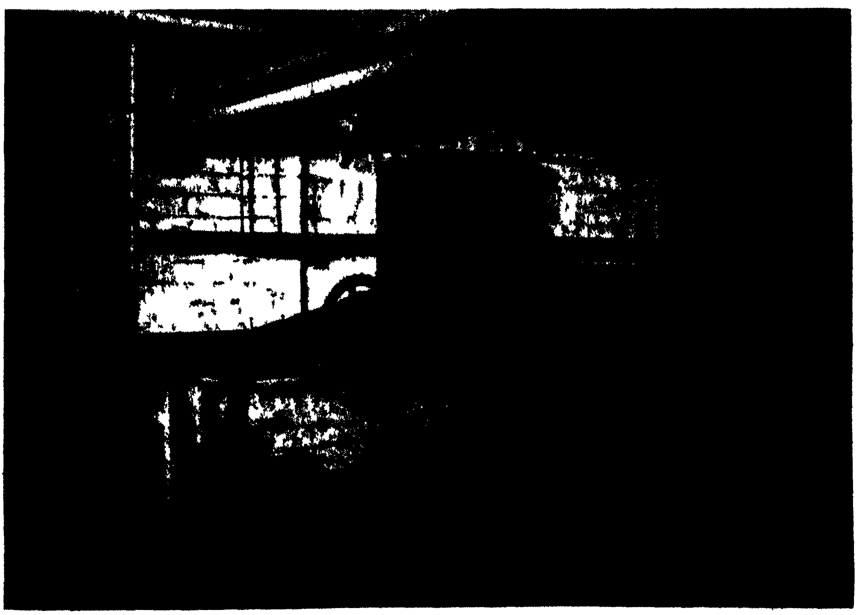

FIGURE 16.

FIGURE 17.

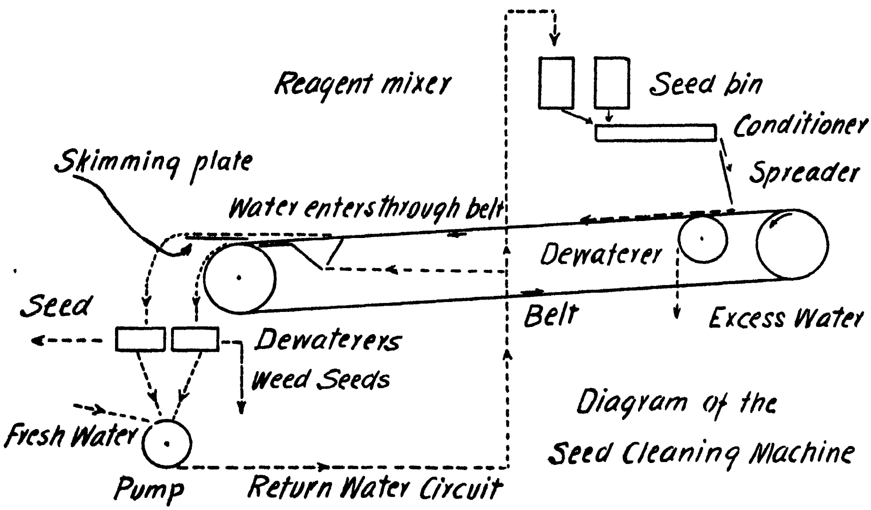

FIGURE 18.

(Figure 16) was placed in the plant of a professional seed cleaner and was operated by the ordinary plant staff. The machine was not operated continuously and chiefly at night, but in the two years it has been in use, it has treated over a million pounds of seed, made up of many small lots and has proved that the process is commercially practicable.

Operating this machine revealed many mechanical weaknesses, and suggested technical improvements which led to the building of a larger machine (Figure 17). The general scheme is shown by Figure 18, the most notable feature of which is the elimination of the large tank of water used in the earlier machine. This change made possible or necessary other changes, of which some of the details are given in the following sections.

Conditioning

This term denotes the preliminary preparation of the seed by wetting with water; or by wetting with water containing a wetting agent to increase the wetting properties of the liquid; or by water in which an oil or other substance has been mixed to decrease the wetting of the clover seed. With most lots of the seed under consideration, wetting with ordinary water is sufficient.

The early conditioning machine consisted of a screw conveyor in a pipe into which the seed and water were admitted. This type was abandoned because the seed flow depended on the water flow rather than on the screw. If the flow slowed up by reason of too little water, or too much seed, the swelling of the seed blocked the conditioner. A feed screw in an open trough gave better results but would give a steady discharge only with a thick feed. The flotation results using this conditioner were erratic and it was abandoned. Tests with these conditioners showed there was something lacking in the completeness of the wetting of the campion and catchfly seed. Immersion in water for a considerable time, up to several minutes, was not always sufficient. It was found that to wet these two seeds, bladder campion and nightflowering catchfly, properly, a period of violent agitation was required. To provide this agitation, the screw of the conditioner was replaced by a shaft equipped with many paddles and revolving at a fairly high speed. It was necessary to depend on the conditioning water to effect transport through this machine. This conditioner worked fairly well; subsequently other experiments showed that so long as the agitation was sufficiently violent for a very short time, any subsequent time of immersion was of no advantage so far as the weed seeds were concerned and only made the clover seed more difficult to float. Given a sufficient degree of agitation, the maximum time required for wetting campion and catchfly seeds is not over 30 seconds and usually is much less.

The present conditioner is a cylinder very short compared to its diameter. It is about 2½ inches long and 9 inches in diameter. The seeds and water enter and leave by central openings at the ends of the cylinder. In the cylinder is a revolving disc on which are pins which pass concentrically between similar pins on the inside end of the

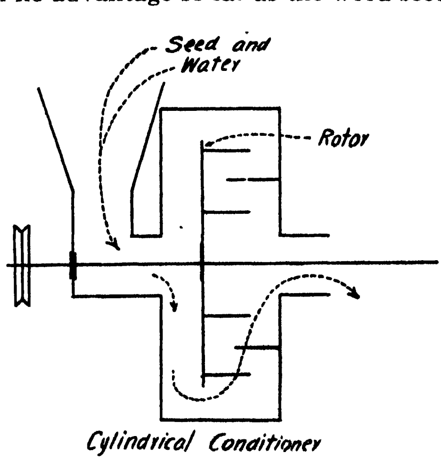

FIGURE 19.

cylinder, at 600 to 800 R.P.M. This conditioner (Figure 19) gives all the agitation necessary. It is easily cleaned, has small storage capacity so there is little delay in the passage of the seeds, and consequently the absorption of water by the seeds is a minimum. There is sufficient clearance in the machine so that the seeds do not become broken nor damaged so that their germination is detrimentally affected.

Effect of Agitation in the Conditioner on Germination

Growing tests on alfalfa and alsike seed after agitation for periods up to 16 minutes did not show a variation in the percentage germination beyond the probable sampling error.

The reason for the necessity of agitation in the wetting by water of the seeds of campion and catchfly can be understood by reference to the photographs of these seeds. The extreme tip of the tubercles is quite different in texture from the hollows. The tips are hard and difficult to wet. The hollows are easy to wet but apparently a film of air is to some extent trapped in the hollows so that the film of water on the wetted seed is not held very firmly, and so the seed easily becomes dry in spots. The specific gravity of the seed is so little greater than that of water that in the case of bladder campion seed, a dry spot covering three or four tubercles may be enough to cause the seed to float with the clover seeds. The violent agitation presumably drives out the air film.

Conditioning Agents

For wetting the seeds of bladder campion, nightflowering catchfly and white cockle, plain water is usually effective when coupled with sufficient agitation. In some lots of seed, the clover becomes wetted too easily and various oils are used to coat the clover seed with a more water resistant surface. The oil is previously beaten up with water to help distribution before adding it to the conditioner. Excess of oil tends to float the weed seeds also, particularly if the seeds have not been previously thoroughly wetted. Several oils were tried. A moderately light oil such as neutral white petroleum was found to be suitable when an oil was necessary. Other oils might have been used except that they failed in some of the requirements such as tastelessness, or had a tendency to rancidity, or stickiness on standing, or had a disagreeable smell. It is better to have no smell at all. The use of an oil did not always prevent an excessive loss of clover seed through too much wetting. Some of the reasons for this loss are discussed later.

Distribution of the Seed on the Belt

In the original larger scale machine, the seed was delivered to the belt under water which made it easy to spread the seed only one grain deep by means of a straight edged scraper. In the later machine without the big tank when the seed was delivered to the belt, the water ran through the belt leaving the seed in heaps. A straight edge scraper spreads the seed one grain deep but trouble was found in keeping the seeds from climbing up on the delivery side of the scraper and then falling off in clots two or three seeds deep on the belt. The objection to these bunches of seed is that the lower clover seeds may be forced under the surface of the water

and be lost with the waste or that weed seed might be rafted on the floating clover seed and be carried into the good seed with the possibility of lowering the grade of the treated clover seed. This bunching was prevented by inserting a strip of wire cloth ½″ wide into the scraper about 1″ above the lower edge of the scraper. This allowed a thin film of water to pass through to the delivery side of the scraper, thereby preventing the seeds from being held by surface tension at the junction of the water surface and the dry side of the scraper (Figure 20).

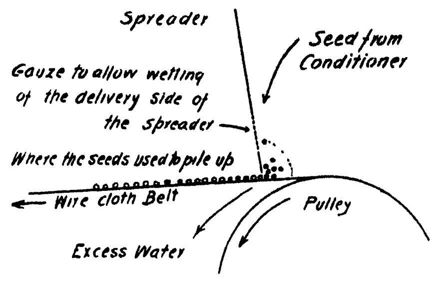

FIGURE 20.

Drying the Seed on the Belt

Most of the water is removed almost as soon as the seed reaches the belt. Part of the water is carried by surface tension in the meshes of the belt and some more as a film over the seeds.

The ideal condition is to have a water film around the weed seeds and none around the clover seed. With the openings of the belt full of water, it takes a long time for the film to dry or to break over the clover seed, so it is desirable to remove any excess water as fast as possible, thereby diminishing the length of belt necessary to give the clover seed a chance to finish drying (Figure 21).

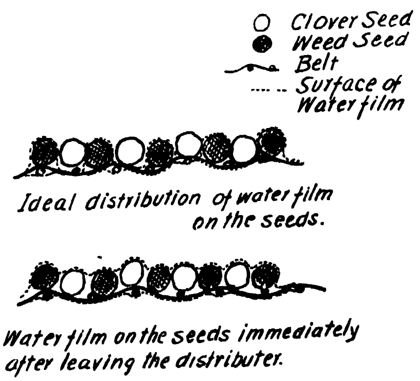

FIGURE 21.

A roller covered with sponge rubber and pressing on the underside of the belt was found more efficient than a vacuum in sucking the water from the seed and the belt. A squeegee roller under the suction roller keeps it from becoming saturated. It is not desirable that the suction roller be quite dry. The suction roller is more positive than a vacuum or than air pressure in removing the excess liquid as it uses the capillarity of the fine pores of the rubber to overcome the surface tension of the water film on the seeds, and is independent of the amount of seed on the belt.

The Separating Bath

The moment at which the seeds reach the water surface of the separating bath is the critical moment during which the seeds part company, the dry ones floating on the surface of the water and the wet ones continuing their way under the water.

To avoid a sudden shock to the seeds from a quick change of speed the bath water is pumped up through the belt which at this point is nearly

horizontal. The travelling belt drags the surface water along with it so that belt and water are travelling at approximately the same speed and with only a small angle between the belt and the water surface. It seems to be important that the change of momentum and the change of direction of travel of the seeds at the point of introduction to the separating water should be a minimum. This way of presenting the seed to the water surface makes it possible to run the belt at high speed, the limit being governed by the time taken for the clover seed on the belt to become dry. The material of the wire cloth belt must be easily wetted. If the belt is not easily wetted, the change of direction from belt to water surface will be abrupt because of the surface tension curve. This water curve coupled with high speed belt travel causes a water wall over which the clover seeds cannot climb, and therefore are forced under with the waste seed (Figure 22).

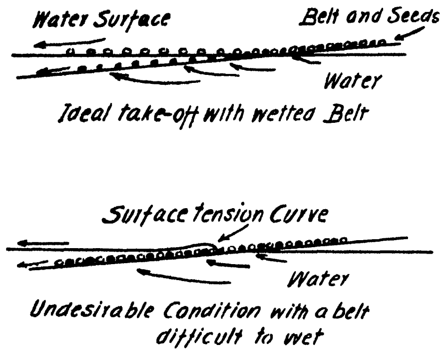

FIGURE 22.

To reduce the tendency of the water to form this undesirable wall, it is preferable to use a wire cloth of comparatively open weave and thoroughly degreased. We have found that a 32 × 32 mesh monel metal ventilator cloth is suitable. When put into service new it requires to be degreased like other wire cloths. After being in use for some time the monel metal takes on a dark coating probably from reaction with some of the products derived from the seed and it then is much more easily wetted than before.

When the seed is once divided into two layers, "floats" and "sinks", it is easy by means of a horizontal splitting edge just below the surface of the water to conduct these layers into different channels for de-watering the seed.

Drying the Seed after Flotation

The flotation process being one in which the seeds are wetted, the question arises as to whether the seed will absorb enough water in the few seconds during which the seed is under water to affect its keeping qualities.

In practice in a moderate climate, such as Ontario, it has been found that neither the keeping qualities nor the germination deteriorates because of the wetting, provided the seed is de-watered without delay by centrifuging. The centrifuge leaves some surface moisture on the seed which is absorbed in a short time by the seed. Several tests have shown that the total moisture after treatment is about 11% and sometimes less. In the case of wheat the moisture content may be over 14% before the wheat is classed as tough. Some small lots of clover seed with 16 to 18% moisture have been kept in sealers for months without becoming musty, so that around 11% moisture appears to give a safe margin. The cleaned seed may be put into the usual grain sacks without any special drying, and so

far has given no trouble either by heating or going musty provided the bags are stored so that the air can circulate between them. In a warm climate, or if the seed is to go into storage in a large bulk, it might be necessary to pass the seed through a dryer. Also, clover seed dried only by a centrifugal after flotation will lose some moisture and weight under ordinary warehouse storage conditions. If the seed is to be weighed and bagged for market directly after flotation, it should first be dried to normal to avoid subsequent loss in weight.

Some of the Variables in the Operation of the Process

Original Moisture in Seed

One of the differences noted between various lots of seed is the moisture content, which varies with the length of time since the seed was threshed and with the conditions of atmospheric moisture in the place where the seed may have been stored for a length of time. If the seed has been through a cleaning process this also may affect the moisture content. The moisture content would possibly vary the flotability of the seed. Flotation tests show that this is so.

The moisture content of the seeds was determined by loss in weight after drying the seed for three hours at a temperature of 110° C. After adding water and giving time for the water to become distributed, the moisture content again was determined by drying.

To fresh samples of sweet clover of originally 9.4% moisture, enough water was added to raise the moisture content, and after being bottled for three days to distribute the moisture evenly, the seeds were tested by flotation (Table 3).

TABLE 3

Lot No.	Percentage moisture in the seed	Percentage of seed floated	Nightflowering catchfly seed per oz. in float
1	10.3	92.5	364
2	11.6	95.5	428
3	15.4	94.0	652
4	17.2	85.0	1160
5	22.9	83.0	1790

The percentage floated is a maximum at about 11% moisture. In No. 4, the sweet clover was slightly musty which accounts for the large amount which sank. In No. 5, the seed was appreciably swelled. An unexpected result was the steady increase in the amount of catchfly seed floated, which quantity increased with the amount of moisture in the seed.

A further test was made with alsike to check the effect of absorption of moisture from the air. The alsike seed had been stored in a warm dry place for 2 years and then placed in a humidifier to allow the seed to absorb water (Table 4).

TABLE 4

Time in humidifier in hours	Float		Sink	
	Per ce nt	Assay	Per cent	Assay
		per oz		%
None	93.6	22	6.1	50
45 hours	90.72	26	9.28	40
90 hours	96.5	144	3.5	70

The assay is for nightflowering catchfly seed.

In this case as before the catchfly seed floated the better for extra moisture, but so did the alsike. A more definite connection between moisture content and flotability is shown in the next test.

Several 100-gram samples of old alsike were placed in sealers, varying amounts of water were added, and the sealers were closed for 18 days. The samples were then put through the flotation machine. The results are shown in Table 5.

TABLE 5

Water added to 100 gr. seed	Total percentage of moisture	Percentage of alsike sunk
None	7.2 (dry seed)	7.64
0.25 cc.	7.4	6.1
0.75 cc.	7.88	6.77
2.5 cc.	9.4	7.71
5 cc.	11.5	8.55
10.25 cc.	15.62	17.6
15 cc.	18.8	22.0
20 cc.	22.7	76.0 (This lot became musty)

Thus we see that the minimum sink occurs when the moisture content is somewhere near normal. Increase in moisture content over the normal amount increases the percentage sunk, although the seed appeared to be perfectly dry.

Surface Impurities such as Soil, Road Dust, Etc.

One lot of alfalfa seed when treated by flotation on the large machine in the ordinary way gave a loss by sinking of 25% of the seed. The seed was dull in appearance and showed at 10 magnifications a very few small particles of clay sticking to the surface of the clover seed, though none could be seen by the naked eye.

Laboratory tests confirmed the heavy loss. Longer conditioning time with the idea of removing the clay gave results still worse than before, the loss rising to 30%. It was noted that the conditioning water became slightly dirty, so a portion of the seed was placed in a jar and agitated briskly for a couple of minutes with water. The water was decanted and the seeds treated immediately by flotation with a resulting loss of only 10%. The water was filtered and the mud examined microscopically. Some quartz particles were seen and many limestone particles, as well as clay, organic matter, etc. The origin of the seed was not known but it apparently had been grown in a field near a country road from which the dust had been blown by the wind over the clover. In the process of threshing which removed the hulls from the clover the road dust had evidently dirtied the seed. After thorough washing to remove the dirt this seed could then be easily cleaned.

The Effect of Common Salt

There are some processes of seed cleaning that use a gravity separation aided by a heavy liquid, usually common salt solution. The presence of common salt is detrimental to subsequent cleaning of the seed by flotation methods.

Several samples of alsike were received from the Eddy Seed Cleaners, Limited, who reported that they were unable to clean the seed because of a difficulty in floating the seed. From 65 to 70% of the seed would

not float. A check test in the laboratory confirmed the result, 60% being non-flotable.

The past history of the seed indicated the probability that the seed had at some time been treated with a salt solution and that the residual salt in the seed was the cause of the trouble.

The original seed as well as samples of sink and float as produced by the factory were analysed for salt (Table 6).

TABLE 6

Seed	Lot No.	Product	Salt present
			%
Alsike	S.B.B.	Original feed to flotation machine	0.39
Alsike	S.B.B.	Float from flotation machine	0.024
Alsike	S.B.B.	Sink from flotation machine	0.045
Alsike	Lot X	Check sample from another lot	None

Common salt was found where there normally is none. The reduction in salt content in the "float" and "sink" is due to the washing of the seed while passing through the machine.

Several attempts were made to thoroughly wash the salt from the alsike and then make a separation. Also, it being possible that the washing would have allowed the seed to soak up enough moisture to spoil flotation, the seed was dried in various ways after washing and before flotation (Table 7).

TABLE 7

No.	Seed	Lot	Procedure	Total seed sunk, %
1	Original feed	Alsike S.B.B.	Washed salt free, treated on machine while still wet. No oil or conditioning agent used.	43.5
2	Original feed	Alsike S.B.B.	Washed and seed dried quickly on a hot-plate. No oil.	45
3	Original feed	Alsike S.B.B.	Ditto but with slower belt speed to help flotation.	35
4	Original feed	Alsike S.B.B.	Like No. 3, but seed dried 3 days in air before flotation.	45
5	Check	Alsike LX	Check with salt free seed. Conditions as in Exp. 1.	10 (5% Alsike) (5% weed)

Washing until the washings were sufficiently salt free to give no reaction with silver nitrate did not restore the original condition.

The supply of seed, alsike lot S.B.B. being exhausted, tests were continued by salting other fresh seed. The seed in weighed amounts was immersed in concentrated salt solution, whirled in a Babcock centrifugal machine for various times to ensure thorough wetting, drained, washed and floated (Table 8).

TABLE 8.—EFFECT ON FLOTATION OF TIME OF CONTACT OF SEED WITH COMMON SALT SOLUTION

Time of contact of seed with solution of salt	Percentage of total seed sunk on flotation after drying			
	Very quickly on hot plate	3 hours on hot plate	3 days without heat in air	No drying. Fed wet to machine
1 minute	39	22	74 1	10.7
2 minutes	44.2	—	74.8	14.9
3 minutes	51.9	—	82.7	20.9

In each case longer contact with salt solution caused a larger percentage of the clover seed to become unflotable.

That this loss is not due to the absorption of moisture by the seed during soaking can be seen by reference to the tests on the effect of moisture where after two days in the humidifier the loss on flotation was less than 10%.

From these tests it is evident that treating the seed with salt is detrimental to flotation; that the detriment is greater with increase in time of contact with salt; that once the seed is sufficiently salted washing will not restore the flotability; and no amount of drying will bring the flotability back to its original amount. Also, that if the time of treatment with salt is sufficiently short the amount of sinks may still be within commercial limits.

Heated Conditioning

It being known that temperature has a marked effect on surface tension the result of applying heat to the conditioning water and to the drying seed on the belt was tried. Heating the conditioning water might be expected to work in two ways, by helping to disperse the conditioning agent if any is used, and by hot water having a greater wetting effect than cold water. The application of heat to the seed on the belt would hasten, perhaps preferentially, the drying of the various seeds.

The tests were made on a sweet clover and the results applied later with marked success to a large shipment of a refractory alsike seed. Subsequent tests show that the application of heat to the conditioning water is not always advantageous.

The sweet clover was, to begin with, difficult to float as shown by experiment 1 of the following table. When floated with no conditioning reagent and the conditioning temperature at 10° C., 49% of the seed sank compared to only 0.8% sinking under identical conditions except that the temperature was raised to 75° C. A similar marked change occurred where treating an alsike seed with hot conditioning water containing oil. A change in temperature of the conditioning water from 12° C. to 75° C. decreased the percentage of seed sunk from 24.5% to 2.5%.

A series of tests using various methods of applying heat to the seed, such as heating the conditioning water, or heating the seed with steam or hot air while on the drying belt, showed that heat may be desirable and does not damage the seed during the short time of exposure if the temperature of the seed does not rise above 80° C.

From results obtained in experiments on sweet clover seed containing 22 campion seeds per ounce, we found that the application of heat, either by heating the conditioning water or steaming the belt, is very beneficial with some lots of seed in the separation of campion seed from sweet clover seed, whether a flotation reagent is used or not. Similar results were obtained when alsike seed containing 125 catchfly seeds per ounce received heat treatment. Under normal conditions over 60% of the alsike seed was unfloatable. The reagent used was a 1 to 1 carbon tetra chloride petroleum mixture concentration of 1 part in 400 of water (Table 9).

The increase of temperature in conditioning reduced the loss of alsike seed from almost 68% to less than 2%, the cleaned seed containing less than 5 nightflowering catchfly seed per ounce, the grade being raised from "rejected" seed to grade No. 1. However, raised temperatures were not always advantageous. On some lots of seed it made no particular difference to the separations. In other cases, while the heat treatment aided the flotation of the clover seed, it also hindered the sinking of the weed seeds spoiling the concentration. It was found also, that the easiest method of heat treatment was by heating the conditioning water, and it was also more effective, particularly when a flotation reagent was used.

TABLE 9

Temperature of conditioning water		Sunk, %	Float assay compion
10° C.	*No reagent*	68.0	6
10° C.	Reagent used	18.4	5
45° C.	Reagent used	6.5	10
75° C.	Reagent used	2.48	6
85° C.	Reagent used	1.63	3

The tests in Table 10 show that the undesirable effect that may follow heated conditioning. The seed was Canadian red clover screenings containing about 7000 dodder per ounce, the reagent water-glass, 1/600, and citronella was used in the flotation bath.

TABLE 10

Temp.	
15° C.	41.4% sunk, 4800 dodder per oz. in float.
50° C.	30.0% sunk, 7200 dodder per oz. in float. All the dodder seed floated.
85° C.	Only about 0.1% sunk. Practically all the seeds floated.

To summarize briefly, we have found heated conditioning sometimes beneficial in the separation of campion and catchfly seeds from sweet clover and alsike seeds. Why each kind of seed does not always react the same way to heat treatment is not known. The surmise that the heat aided the distribution of the oil used as a conditioning agent may be true, but it is not the prime cause.

Fouling of Water Circuit by Seed Extracts

When clover seed and some of its associated seeds are scaked in water several materials are dissolved out of the seed by the water. In course

of time these substances accumulate in the water circuit of the flotation machine unless considerable fresh water is continually added. These extracts have a decided effect on flotation. From sweet clover seed is extracted cutin and coumarin, and from alsike a green colouring matter; Bladder campion and nightflowering catchfly seeds are a source of saponin.

These substances may act by reducing the surface tension of the water at the separation end or by increasing the wettability of the seed at the conditioning end. In either case, the floating of the seed is hindered with increased losses.

The effect seemed to be more pronounced with sweet clover seed than with other varieties. Tests were made with sweet clover seed to determine the seriousness of this contamination. Some of the results obtained, using seed extracts as conditioning agents were as follows. Weighed quantities of seed were immersed in 5 litres of water for 1 minute at 85° C. The resultant extract was diluted to 5 litres and used in the conditioning circuit, with the temperature maintained at 85° C., and the separating bath temperature 10° C. The seed was mixed sweet clover containing 450 catchfly and campion seeds per ounce.

The result of the seed extracts accumulating and fouling the separation water is to increase the percentage of clover seed floated and at the same time to increase at a greater rate the percentage of the weed seeds floated. As the fouling became greater, the percentage of clover seed floated became less, with the weed seeds declining in flotability at a slower rate. The net result is that the substances dissolved from the seeds, while being conditioned, caused the grade of the floated seed to become poorer. The curves (Figure 23) show the reversal which suggests that there may be

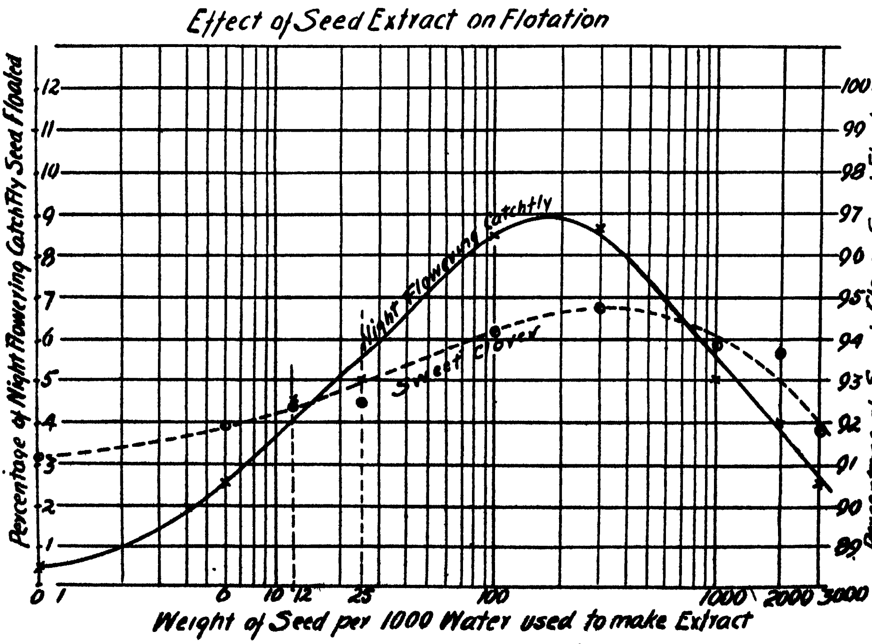

FIGURE 23.

more than one substance dissolved from the seed and which act in different concentrations. These substances must lie close to the surface of the seed in order to be extracted in the short time the seed is wet during the flotation process. In the case of sweet clover, the colouring matter seems to be the first to dissolve, followed by coumarin, which gives sweet clover its characteristic smell. Staining tests followed by microscopic examination of sections show that coumarin lies almost entirely in the layer of Malpighian cells, the second row from the surface, and therefore is easily extracted. The campion and catchfly seeds are sources of saponin, which is a decided reducer of flotability. The coumarin in solution increased in quantity up to test 6 and then was approximately constant.

Polishing and Flotation

In the flotation of clover seed, particularly sweet clover seed, it frequently happened that a small percentage of the seed stubbornly refused to float, even though the bulk of the seed gave no trouble. An attempt was made to find a reason therefor.

It was noticed that seed that had gone through a scarifier had a tendency to be more difficult to float than unscarified seed. This suggested that in the passage through the scarifier the seed surface was rubbed or abraded. To produce a surface change on the seed to a maximum degree on small samples, a polisher was constructed following the general lines of a polisher in the plant of the Eddy Seed Cleaners. The photographs show the construction of the machine (Figures 24 and 25). The

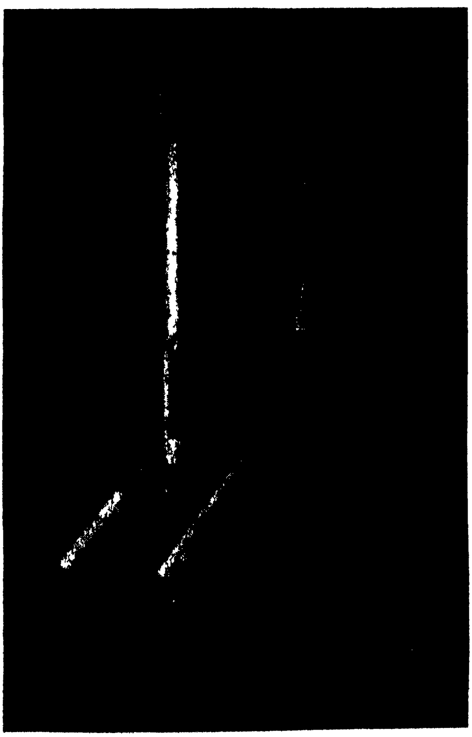

FIGURE 24.

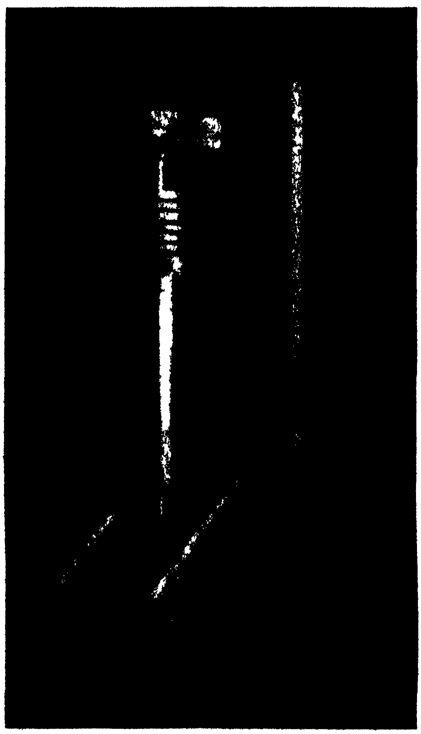

FIGURE 25.

weights shown are equivalent to the weight of a column of seed 4 feet high. The revolutions of the spindle are sufficiently slow (125 R.P.M.) as not to produce any breaking or deformation of the seed. Because some lots of seed are originally very dirty, covered with gritty road dust, some lots of seed were polished after mixing with sand, some after mixing with very small chilled shot (−48 mesh), and others without the addition of anything.

During the course of polishing a dark powder is produced, presumably the outer coat of the seed. This dust is easily removed from the seed by dry wiping or by washing with water. On removal of the dust the seed seems as bright as the original seed (Figure 26). There is no apparent change so far as visual examination is effective. That there is a change is shown by the marked decrease in the flotability of the polished seeds.

FIGURE 26.
Not polished. Sweet clover seed. Dry polished.

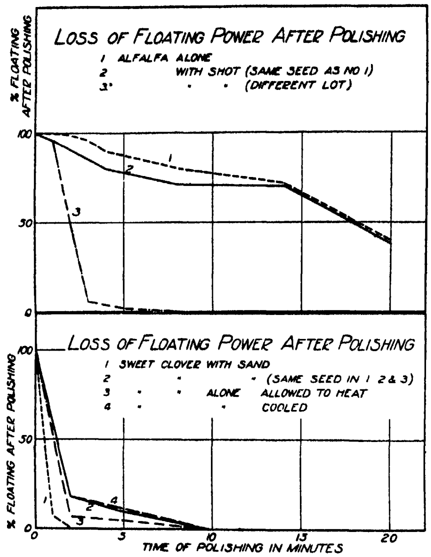

FIGURE 27.

The curves of Figure 27 give an idea of the extent of these changes. The figures from which the curves are drawn are only approximations because of the errors of sampling and because of small changes in technique. The results, however, show very decided trends along the following lines.

(1) Rubbing the clover seed changes or damages the outside layer.
(2) The floating power decreases with increase of rubbing or polishing.
(3) Raise of temperature while polishing increases the rate at which flotation decreases.
(4) The presence of grit increases the rate at which flotation decreases after polishing.
(5) With the same kind of seed, different lots vary in the effect of polishing.
(6) The average loss of floating power due to polishing of one kind of clover seed may be quite different to the similar loss of another kind of clover seed.

These results give one explanation of why the clover seed, in particular sweet clover seed, may be at times difficult to float. The sweet

clover seed coat appears to be more delicate than the coat of other clover seeds and therefore suffers more in threshing and also in scarification for the treatment of hard seeds. Sweet clover seed more than other clover seed may require scarification to increase germination. Subsequent experience on commercial lots of seed confirms the detrimental effect of polishing by friction on the flotation of clover seeds.

Another commercial method of polishing seed is by giving the seed a slight coating of paraffin oil, not enough to make the seed sticky nor feel oily, but just enough to remove the dull appearance of the seed. The seeds are dry at the time of mixing with the oil, therefore the weed seeds as well as the clover seeds become oiled, removing the natural differences of wettability and making separation by the flotation process impossible.

For example, a lot of yellow blossom sweet clover seed containing 85 bladder campion and catchfly seeds per ounce was treated in the usual way with a resulting loss of 35% of the clover seed. When conditioned with oil and the conditioning temperature raised to 50° C., the loss in the sinks was still 30%. Testing this seed in the laboratory under various conditions of temperature and with different reagents showed that the difficulty lay with the seed and not with the operation. The smallest loss of seed obtained was 9%. In all the tests of this seed the loss was very high. The best results were obtained by using a considerable amount of oil to float the clover seed and adding a wetting agent to sink the weeds. Heating the conditioning water above 50° was of little or no advantage. A moderate increase of temperature aided by improving the distribution of the heavier oil. A longer drying time than usual reduced the percentage loss but at the expense of the grade of the float. This seed was very dull in appearance, though washing with water gave no signs of earth or dirt. Filtering the wash water and microscopical examination of the solids showed considerable cuticle that had been removed from the seed. Judging by the results of friction polishing this seed had received rough treatment, possibly by being threshed before it was properly cured; consequently it was difficult to float.

Germination after Polishing

Some lots of clover seed after being floated and dried are improved in appearance by polishing. Advantage was taken of some tests on the effect of polishing by friction on the flotation of clover seeds to see what difference this mechanical polishing would have on the germination of the polished seed.

Some lots of red clover seed that had been polished were tested for the proportion of hard seeds after various times of polishing. The curves of Figure 28 give the results. With this seed there is an early reduction in the number of hard seeds while long continued polishing makes little further reduction.

The germination of clover seeds depends on the penetration of water into the seed at the region called the strophiole[4]. Hamly shows that in a hard seed a small blow in the region of the strophiole is sufficient to allow water to enter and permit germination. He shows that severity of impact is not necessary. Scarification by breaking the seed coat also allows water to penetrate the seed but causes many damaged or weak seedlings.

[4] Softening of the seeds of *Melilotus alba*. Douglas H. Hamly, Botanical Gazette—Vol. XCIII—1932.

If the same softening can be obtained by putting momentary pressures on the strophiole the hardness could be reduced without damaging the seed. This the polisher appears to begin to do, but not to the extent that might be expected.

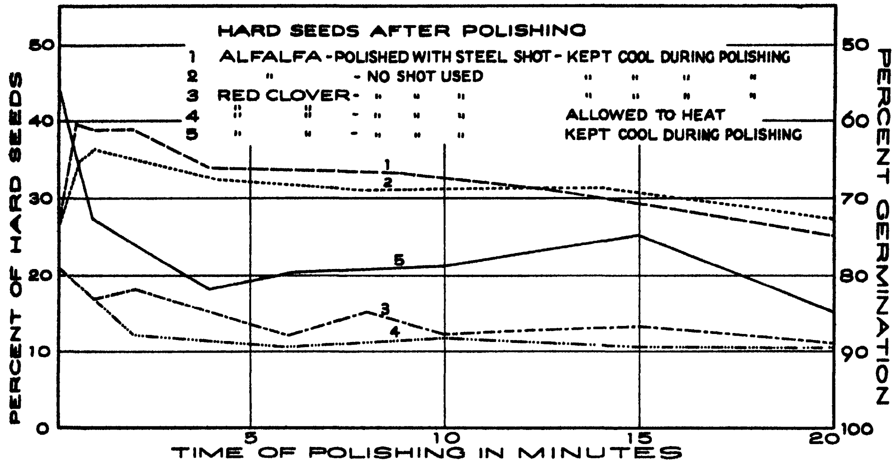

FIGURE 28.

It is assumed that the incompleteness of the softening is possibly due to the fact that the strophioles are to a considerable extent protected from being pressed by the other seeds because of being somewhat in the hollow of the clover seed (Figure 29). If the seed be mixed with smaller particles that can enter this hollow to squeeze or impact the strophiole, then more complete softening might be expected from the use of the polisher.

FIGURE 29.

Germination tests were therefore made on a sample of sweet clover seed that had been mixed with an equal volume of well rounded sand size 14/28 mesh and then put through the polisher. Counting the hard seed brought out the unexpected fact that instead of a decrease there was an increase in the number of hard seeds for the first minute or two of polishing, and then a decrease to about the original percentage (Figure 30, curves 1 and 2). The decreased hardness shown by curve 3 is what might be expected from the statements of other workers on the effect of heat on the hardness of seeds[5], that a moderate raise in temperature aids the germination of clover seeds. In one test on alfalfa (Figure 28, curves 1 and 2) very small chilled cast iron shot (35/65 mesh) was used instead of sand with similar results.

[5] Ewart, Miller, Harrington, Lute. (See Hamly's bibliography.)

From these results it may be judged that the effect of the polisher was in the first place to plug the strophioles in some way thus increasing the hardness. This effect is more apparent on some lots of seed than on others though whether the difference is inherent in the different kinds of seeds or only depends on which lot of seed was used is not known. However, this shows that the mechanical polisher must be used with discretion.

Curves 1 and 2, Figure 28, and curves 1, 2 and 3 of Figure 30, the curves of alfalfa and sweet clover seeds, each indicate an increase in the number of hard seeds in the first minute or two of polishing. Curves 3, 4 and 5, Figure 28 of red clover, show a decrease in the number of hard seeds in the first minute of polishing. No attempt was made to determine if the difference between the red clover seeds and the other seeds was specific or was due to some peculiarity in the conduct of the experiments.

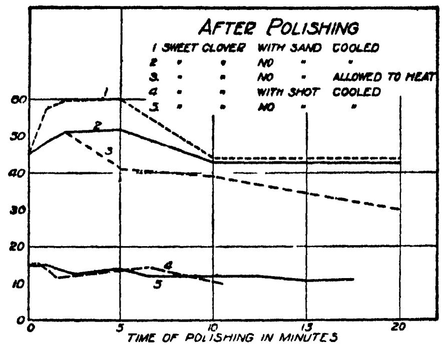

FIGURE 30. Hard seeds

This increase in the hardness of seeds produced by the polisher is unfortunate for it was proposed to use the polisher to make clover seed unfloatable in the separation of it from some hard coated seeds on which the polishing has little effect.

During the polishing, the cuticle was removed without making any great difference in germination properties while having at the same time a marked effect on the surface wettability. Flotation and germination are therefore totally unrelated phenomena.

A Quick Test for Hard Seeds of Sweet Clover

The usual method of determining the hardness of clover seed, particularly of sweet clover, is to make a germination test of the seeds by keeping them moist between blotting papers in lots of 100 or 200 and counting the number that fail to sprout or show distinct signs of swelling. For clover seed the count is made at the end of three and of five days. For the seeds to swell, water must penetrate the seed coat either through the strophiole or through breaks in the seed coat. Seeds that show no signs of swelling after 5 days are considered to be hard seeds. A more rapid test may be used where hardness and viability may be considered to be synonymous or in new seed where the life of the seed may be taken for granted.

If the seeds are soaked for a few minutes with a weak solution of ferrous sulphate or other iron salt and then dried in air, the outer coat remains colorless. If the solution can penetrate to the inside of the seed the ferrous sulphate in a few hours will turn the inner seed coat jet black, so that a black spot on the seed indicates a place where water can soak in and therefore black spots on a seed indicate that it is not a hard seed. Under this test hard seeds retain completely their natural colour.

Many checks made of this method against the ordinary germination method all showed that differences if any were within the probable sampling error.

This is a ready test for hardness in light coloured clover seed when the hardness and not the total viability of the seed is required.

Natural Variations and Flotability

Experiments have shown that some of the causes of the difficulty in floating all the sweet clover seed are: (1) the result of polishing or rubbing in the process of threshing or some subsequent treatment; (2) the presence of dust and dirt on the seed, probably road dust from fields near the highways; (3) a third reason was found in a few lots to be the presence of common salt retained from a previous operation; (4) another cause of unknown origin is the one that can be removed by heat treatment. These reasons do not altogether explain the reluctance of a portion of the sweet clover seed to float. It was thought that there might be some chemical difference between the varieties and strains of the sweet clover, which might appear in the reactions of the seed.

Yellow and White Blossom Clovers

Tests on lots of pure white blossom and pure yellow blossom seed showed that one variety contained no more coumarin than the other, and the flotability of the two kinds was about the same.

Bitter and Sweet Strains of Sweet Clover

There are two strains of sweet clover, a bitter strain and a sweet strain. This bitterness is associated with the presence of coumarin. It was thought possible that there might be some association between the bitter and sweet strains and the flotability of the seed. When J. S. Clayton and Professor Larmour[6] developed a quick method for the determination of coumarin, tests were made on various seeds to see if flotability was connected with coumarin and possibly other connected chemical differences.

In tests on several pairs of sinks and floats we find that the float in many cases contained more coumarin than the sink, but not always, indicating that the chemical properties associated with coumarin were not the cause of persistent sinking.

Hardness and Flotability

The tests on polished seed show that the induced hardness of sweet clover seed due to polishing by friction is accompanied by loss of floating power. It does not follow that the original hardness is connected in any way with flotability. Tests for hardness on the sink and float of a clover seed known to contain considerable hard seed showed that there is no direct relationship between the natural hardness of the seeds and their flotability.

THE SEPARATION OF DODDER SEED FROM CLOVER SEED

There are several species of dodder of which it is difficult to differentiate the seeds, so a rough classification is made into large seeded and small seeded dodders according to whether or not the seed will pass a screen of one millimeter opening. The small dodder seeds can usually

[6] A comparative color test for coumarin and melilotic acid in *Melilotus* species. J. S. Clayton and R. K. Larmour. Canadian Journal of Research, C. 13 : 89-100. 1935.

be removed from clover seed by screening. The seed of the large seeded dodders presents more difficulty, yet it is essential that dodder be absent from good seed, for both in Canada and the United States of America and elsewhere it is classed as one of the worst weed seeds to be found in clover.

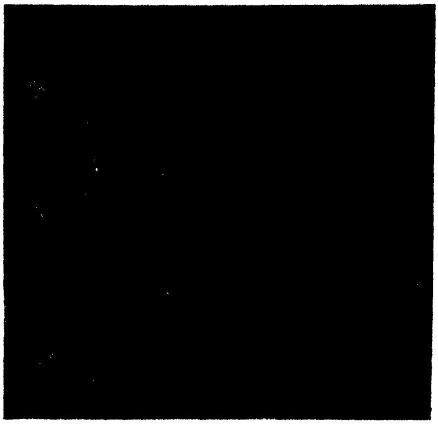

FIGURE 31. Large and small dodder seeds.

All of the known methods of separation of dodder from clover seed depend on the minute roughnesses of the dodder seed coat, Figure 31. In one method the depressions in the seed coat are filled with a specially prepared magnetic material so that the seed can be lifted with a high powered magnet. In another process the slight differences between the rough dodder seed and the smooth clover seed are used to produce by friction a differential throw of the seeds when allowed to fall onto a fast moving surface faced with velvet. Another method feeds the seed to a trough formed by two rolls covered with fabric and rotating in opposite directions at a comparatively slow speed. This by repeated treatments brings about a progressive improvement in the separation to the point where a clean product can be obtained. These methods tend to give considerable middling product. Another disadvantage is the small capacity.

The authors considered it desirable to find another method that might give better results and one that would remove dodder seed at the same time as bladder campion, cockle and similar seeds.

The flotation process proved successful in the case of bladder campion and night-flowering catchfly seeds, so an attempt was made to apply the same principles to the separation of dodder seeds from clover seeds.

The simple wetting and flotation process that served for night-flowering catchfly did not prove as successful when applied to dodder. Just as with the campion-catchfly-cockle seeds, vigorous agitation was found to be necessary in wetting the dodder seed and probably for the same reason. Agitation was therefore made a part of the standard procedure similar to the method outlined previously. Most of the tests were made on a test tube scale, any tests that showed promise being repeated on a larger lot of seed.

Of the chemical nature of the cuticle of the clovers very little is published[7] and even in that little the authorities do not always agree. About the outside of the dodder seed still less is known so that the only fact with a bearing on flotation on which to build a system of experiments is that the dodder seeds like the nightflowering catchfly seeds, but to a smaller degree, are more easily wetted by water than are the clover seeds.

[7] A. M. Lute. Impermeable seed of alfalfa. Bull. 326, Colorado Exp. Station.

D. H. Hamly. Softening of the seeds of *Melilotus alba*. Bot. Gazette, Vol. XCIII, 4. 1932.

A. M. Anderson. Preliminary michrochemical study of the seed coats of Grimm Alfalfa and Red clover. Bot. Soc. of Am. 1930.

The tests were made along the following lines:

(1) To increase the difficulty of wetting the clover seed so that the dodder seed might be made to sink.

(2) To decrease the surface tension of the water bath.

(3) To use a reagent to increase the wettability of the dodder seed compared to the clover seeds.

(4) To increase the specific gravity of the dodder seeds.

Previous tests had shown that it is possible to decrease the wettability of clover seed by the use of paraffin or similar oil. However, paraffin instead of increasing the difference of wettability between dodder seed and clover seed increased the flotability of the dodder seed so that in some tests the differential of wettability between the seeds disappeared and both seeds floated together.

Decreasing the surface tension of the bath aided dodder to sink more readily, but also, though not quite to the same degree, helped the clover seed to sink. The lowered surface tension of the bath by itself was not sufficient to make a good separation possible though as will be seen later controlling the surface tension of the bath may be advantageous when used in conjunction with other factors.

Raising the temperature of the conditioning water improved the separation to some extent but still a considerable portion of the dodder seed persistently floated. With a sample of red clover containing about 500 dodder seed per oz., using a conditioning temperature of 75° C., and a belt speed such that 1.8% of the seed was sunk there remained 180 dodder seed per oz., in the float. When the belt speed was increased so that 6% of the feed was sunk there still remained 118 dodder seed per oz. in the float. Raising the temperature of treatment by itself was not enough to ensure a separation.

Flotation tests were made on Canadian red clover, Canadian red clover screenings, and on American red clover screenings. Tests were made on each seed with the conditioning both hot and cold, with water glass as a depressant, with petroleum as floating agent, with citronella in the separating bath to reduce its surface tension, and several combinations of these, without approaching nearly to the degree of separation required. Some other factor was evidently required.

To use a conditioning agent in order to increase the wettability of the dodder seed to a greater degree than that of the clover seed seemed to be the most promising method. As a slight guide to the choice of reagents to be tested the reagents at first were grouped as those that would chemically attack or dissolve (a) cellulose, (b) fat, (c) lignin. Since the Maule colour test did not give any reaction with the dodder seed coat, and those reagents such as chlorine water, potassium permanganate, which attack lignin, did not aid the separation, it is assumed that lignin is absent from the seed coats.

Not all of the reagents and combinations tried are mentioned below; only a few out of the sixty odd to indicate the trail followed.

Of the cellulose group, zinc chloride and caustic soda were of no benefit• Schweitzer's reagent (copper dissolved in ammonia) made possible a fair separation. The reagent stained the dodder seed but not the clover seed.

Although the reagent for chemical and economic reasons would not be suitable in practice it confirmed the possibility of there being some other reagent that would increase the differential flotability between the clover and dodder seeds by making the dodder seed the more wettable.

Carbon tetrachloride, a fat solvent, allowed some separation but acted mainly as an oil in reducing the wettability of the seeds. Trichlorethylene made no particular difference. The oxidizing agents, sodium peroxide and chlorine water were of no advantage, though hydrogen peroxide gave a slightly greater differential in the wettability of the two classes of seeds.

Another line of attack was to attempt to precipitate an easily wetted substance preferentially onto the dodder seed. Most of the tests gave negative results. A few showed a possibility. Precipitating cellulose from solution in Schweitzer's reagent by acid in presence of the seeds allowed a fair separation by flotation to be made. Treating the seed with a wash of barium chloride followed by sodium sulphate improved the separation, though both barium chloride and sodium sulphate were classed as being of no use when either was used alone.

Boiled wheat starch though effective in the treatment of some silicates proved to be useless, as did starch hydrolyzed by caustic soda. Starch hydrolyzed by hydrochloric acid permitted a better separation than was possible without any reagent in the water of the conditioner.

Still following the basic idea of anchoring a film of water around the dodder seed more firmly than around the clover seed, the seeds were rolled in powdered calcium chloride in the expectation that the slightly rougher dodder seed coat would take up the powder more readily than the smooth clover seed. By passing the seed dusted with calcium chloride through a fog made from cooled steam the chloride being very hygroscopic would take up water and therefore the dodder seed should become wetter than the clover seed and it might be expected that the dodder seed would thereby be helped to sink in the separating bath more readily than the clover seed. What actually happened was that both seeds, the dodder as well as the clover, became more difficult to sink and every seed floated. No attempt was made to find the reason for this surprising result.

In the laundering and dyeing industries great advances have been made in the use of chemical detergents and wetting agents as replacements for soap. Some of them such as the sodium silicates are well known, others are of recent origin and new ones are still coming on the market. Samples of many of these were obtained and tested.[8]

Of the sodium silicates, water glass S. brand gave the best results, giving a cleaner float and a smaller sink than the bi- and meta-silicates. Probably this is due to the higher alkalinity of their solutions which would also account for the greater discoloration of the clover seed by the bi-silicate and meta-silicate than when using water glass as a conditioner.

Most of the detergents were quickly eliminated, some on account of the large quantities required to make any appreciable change, others on account of negligible results up to the point of solubility of the material in water and similar reasons. The most promising ones were those sold under the trade names of the Gardinols, Dupolols, Avirols. Chemically

[8] The sodium silicates were from E. T. Sterne & Co., Brantford, and other washing compounds were obtained through the courtesy of Mr. H. Eastwood of Canadian Industries Limited.

these are sodium alcohol sulphates differing according to the particular fat used in their manufacture.

Small quantities of the mixed seeds were wetted with solutions of the reagents up to 10% strength or up to the limit of their solubility in hot water. The wetted seeds in each test were spread on a piece of gauze, the excess moisture removed by wiping the underside of the gauge with a towel, and then introducing the seeds to the surface of water. The number of dodder seeds and of clover seeds floating were then counted and the percentage plotted. While these results may not be as exact as if made on large samples, the results were sufficiently good to be made a basis for eliminating the less suitable reagents. The most promising of these reagents are the Gardinols which gave a larger differential in the sinking of dodder and clover seed with a smaller quantity of reagent than the other materials tried.

The Gardinols

Each of them wets the dodder seed more completely than the clover seed. The wetting properties increase with the strength of the solution, but there are marked differences between their differential wetting properties as shown by Table 11 and the curves of Figure 32.

With increasing strength of solution the differential wetting becomes less. Since the object is to obtain the greatest degree of wetting of the

TABLE 11

1% solution of	Gardinol WA.	Gardinol CA.	Gardinol LS.
Clover floated, %	55	75	60
Dodder floated, %	10	22	50
Differential	45	54	10
2% Solutions			
Clover floated, %	33	40	43
Dodder floated, %	4	10	22
Differential	29	30	21

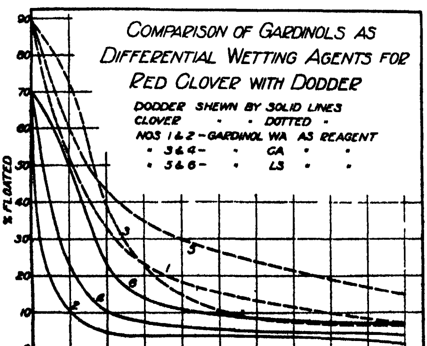

FIGURE 32.

dodder seed and at the same time the greatest differential, the results with Gardinol WA and solution strength from 1% to 2% appear the most promising.

In wetting cotton goods Gardinol CA has proved more efficient than Gardinol WA in hot solutions, but in parallel tests to those cited above Gardinol CA invariably gave poorer results than Gardinol WA and consequently was discarded with the other reagents.

Gardinol WA seems promising provided the percentage of clover seed wetted can be reduced without losing the wetting effect on the dodder seed.

The Use of Oil

Previous work has shown that paraffin oil is adsorbed by clover seed making it more difficult to wet, but dodder appears to have the similar characteristics as is shown by first treating the seed with Gardinol and then by various oil water emulsions.

Oil Water Emulsion, Following Gardinol WA

Parts of water to 1 of oil	500	1000	2000	4000	12,500	40,000
Clover seed floated, %	94	91	89	85	80	60
Dodder seed floated, %	90	87	87	70	22	10

Oil, Water and Gardinol Emulsified Together

Treating the seed with 1 oil in 20,000 water emulsified by G. WA increased the differential but floated more dodder.

Oil Water Emulsion Followed by Gardinol

Treating the seed with oil-water emulsion first (1 oil in 20,000) and then by Gardinol WA 2% sol. increased the differential, but still 16% of the dodder seed floated. The use of paraffin oil apparently requires careful control if used at all and tends to float dodder in spite of the depressing effect of the Gardinol (Figure 33).

The Effect of Heat

Heating the conditioning water has in some cases been found beneficial. Tests were made with 1% and with 2% Gardinol solutions, no oil, and

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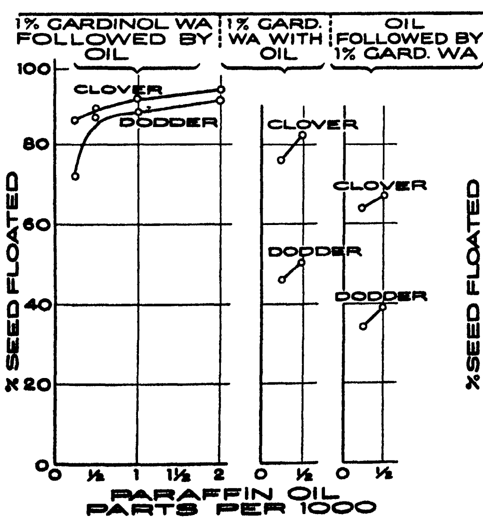

FIGURE 33.

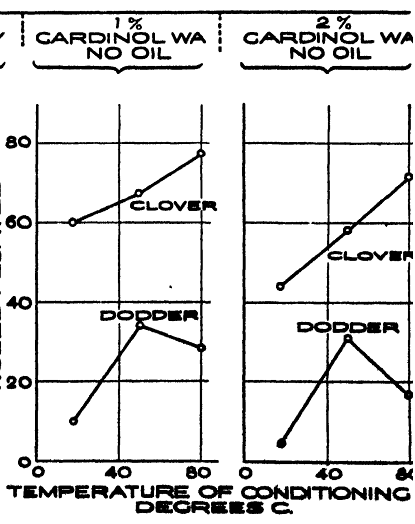

FIGURE 34.

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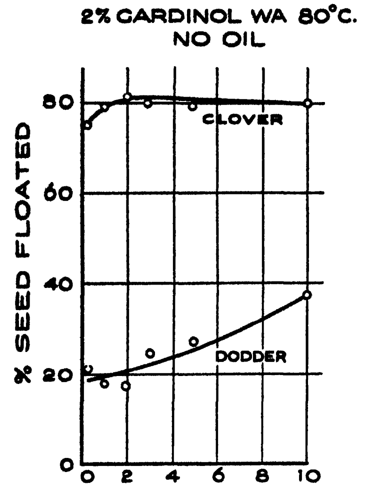

FIGURE 35.

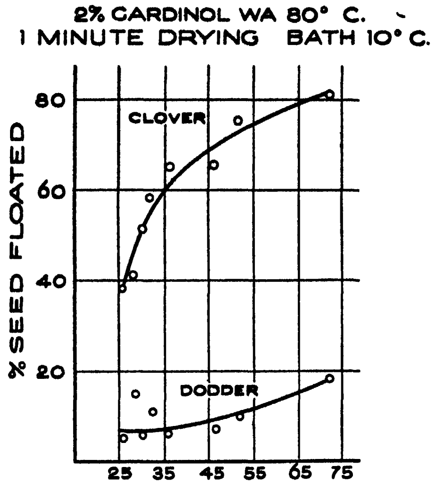

FIGURE 36.

at 50° C. and 80° C. The best result was with 2% Sol. and 80° C. giving a differential of 54% with 16% dodder floating. This is somewhat better than with cold reagent. The addition of an oil treatment gave a poorer result, a differential of 50% with 18% of the dodder floating (Figure 34).

Drying Time

Another factor that may affect the differential between the floating properties of clover and dodder seeds is the time allowed for the seed to dry after conditioning.

In the previous tests the best result was a differential of 54% obtained by using 2% Gardinol solution at 80° C. without oil. These conditions were maintained and the drying time increased. The tests showed that the percentage of clover seed floated remained remarkably constant with drying times varying from 1 min. to 10 min., (Figure 35). Evidently the clover seed which does dry sufficiently to float does so very quickly. The percentage of dodder seed floating decreases during the first 2 minutes possibly due to the absorbtion of water, after which the flotability increases, probably due to drying.

Surface Tension of the Bath

The actual separation of the seeds from each other is a function of the surface tension of the bath. A weaker S. T. would allow a larger proportion of the seeds to sink. The S. T. may be reduced by heating the water. This did not prove satisfactory. A better way is by the addition of a contaminant in which connection Gardinol is very effective. The surface tension figures corresponding to the amount of Gardinol in solution were obtained from the C.I.L. booklet. As might be expected a drop in the amount of both clover seed and dodder seed occurred, the drop in the case of clover being the greater (Figure 36).

Using citronella as a S. T. reducing agent gave practically the same results, a differential of 67% with 9% of the dodder floating.

Washing after Conditioning with Gardinol destroyed the wetting effect of the Gardinol on the dodder, the percentage of dodder seed floating rising from 5–10% to 60–70%.

Increased Conditioning Time might be expected to decrease the percentage of dodder seed floated. Unfortunately longer wetting time increased the difficulty of floating clover seed at a greater rate than it promoted the sinking of dodder seed. The result of several tests showed that from 30 seconds to one minute conditioning time was sufficient.

These tests show that for the separation of dodder seed from red clover seed the best factors found were to condition the seed with a 2% solution of Gardinol WA at a temperature of 80° C. for a period of 30 seconds to one minute, allowing a drying time of not more than two minutes and then separating on a bath at room temperature with a slightly reduced surface tension of about 60 dynes per cm.

The separations made by the standard Gardinol WA treatment outlined above were made with Virginia red clover seed, in which about 5% of the contained dodder seed looked abnormal. This abnormal seed was whiter and smoother than the rest of the dodder seed and was also very much more difficult to wet. There were also many shrivelled and misshapen seeds. The presence of this abnormal seed accounts in some tests for the failure to make a clean clover float. To determine if this condition is common to other lots of seed tests were made as shown in Table 12.

TABLE 12

Feed	Percentage floated			Dodder in float
Clover seed	Dodder seed per oz.	Clover	Dodder	
Canadian red	350	93	3	Abnormal seed
Canadian red (screenings)	5500	95	6	Nearly all abnormal
American red (screenings)	3500	70	10	Abnormal and shrivelled seeds
American red	500	68	0	
Chilean red	100	93	26	Mostly white and shrivelled seeds
Ontario alfalfa	175	91	0	

These results show that most of the dodder seeds that give trouble in the separation are abnormal. The white dodder seeds being sterile should not be counted as weed seeds. Most of the other abnormal seeds were shrivelled or mis-shapen, probably from immaturity; consequently they might be expected to be less dense than normal seed and possibly removable by gravity separation methods. As a small percentage of these abnormal seeds can germinate, however, the shrivelled seeds cannot be ignored.

Specific gravity tests with a solution of common salt, density 1.16, showed that all of the white dodder seeds and nearly all of the shrivelled seeds could be removed by a heavy solution, and suggests that if this small percentage of abnormal seeds were removed the remainder of the dodder seeds could be separated from the clover seeds.

Previously it was shown that treatment of alsike seed with common salt might be detrimental to flotation. Whether the Gardinol would change the effect of the common salt was not known, so the following runs were made using Gardinol WA as the wetting agent, and using common salt solution to remove the abnormal dodder seed. The seed used was a Canadian grown red clover containing 350 dodder seed per ounce.

(1) Common Salt Solution used on original seed. Seed washed with water and transferred wet to the flotation machine; 0.4% of total seed containing 4% of the dodder seed was removed by heavy solution. The clover seeds were brown and shrivelled. The remaining seed was slightly washed and transferred wet to the flotation machine. After flotation 96.5% of the clover seed was recovered dodder free. The sinks were about $\frac{1}{3}$ dodder and 5% of the total.

(2) Parallel tests were made drying the seed after separation by common salt and washing, and before flotation. The separation was not quite as good and 92% of the seed floated instead of 95%. Apparently the drying allowed the salt to permanently affect the seed coat.

(3) Another test in which the specific gravity separation was made on the float instead of the original seed gave a 95% float with a few dodder, 2 per oz., but a smaller quantity of seed was separated by the salt solution. The difference between this test and the first is probably due to a change in specific gravity during flotation. The salt solution does not prevent flotation in this case provided the treatment is done quickly and the salt removed by washing before it has time to soak into the seed.

While with the few lots of seed tested the use of Gardinol WA as a conditioning agent in conjunction with other controlled factors has given good results, it may be that even better reagents will be found when the present method of testing which is necessarily largely "hit and miss" gives way to other methods based on an increased knowledge of the chemistry and structure of seed coats.

Other Weed Seeds Recovered

Mixed in some of the clover seed experimented with were other weed seeds besides those particularly dealt with previously. Seed counts show that some of these weed seeds were partially removed at the same time as bladder campion, nightflowering catchfly, white cockle, and dodder seeds. Results are shown in Table 13.

There is evidently a difference in the seed surfaces suggesting the possibility that if the proper conditioning reagent or other conditions were found, the field of wet separation by surface tension might be considerably extended to cover separations which present commercial operations do not make as completely as is desired.

TABLE 13

Lambsquarters seed from alsike seed	
Lambsquarters in 1 oz. of original seed	348
Lambsquarters in 1 oz. after treatment	179
Black medic seed from sweet clover seed	
Black medic in 1 oz. of original seed	28
Black medic in 1 oz. after treatment	18
Green foxtail seeds from sweet clover seeds	
Green foxtail per oz. in original seed	230
Green foxtail per oz. after treatment	24

SUMMARY

The tests have been confined to separating weed seeds particularly from the clover seeds.

1. The experiments show that there are differences previously unknown in the wettability of the coats of seeds.

2. The differences in some cases is sufficient to allow a good separation using a water bath alone.

3. It is possible to increase the wettability of some seeds more than of others by the use of the proper reagent, and to decrease the wettability of others.

4. The difference in wettability may be increased to such an extent as to make separation difficult by other means comparatively easy by flotation methods.

5. Successful separation has been made from clover of bladder campion, nightflowering catchfly, white cockle, and dodder, and the principle may be capable of extension to other weed seeds.

SUPPLEMENTARY FATS IN THE FATTENING RATION[1]

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In the fattening of poultry the object is to cause a deposition of fat under the skin, perimuscularly in the fascia, on the surface and between the muscles, and also internally in the body cavity. Only slight changes in the amount and character of the muscle fat are effected by the ration fed or the period of fattening. The ration fed, however, shows a marked effect on the character of the depot fats of the skin, the abdomen, and the fascia. Cruickshank (1) has reported the effect of the cereals, corn, oats, and barley, in the fattening ration on the composition of the body fat of immature and mature cockerel stock, showing harder fats being produced with the same cereal in the immature stock as compared with the mature stock. Cruickshank (2) has demonstrated the effect of supplementary fats, such as vegetable oils, on the character of the depot fats. The body fats changed in character according to the character of the oil fed in relatively short periods of time. Maw *et al* (3) have shown that the amount of fat produced by individuals varies widely under similar nutritive conditions, and that the amount of fat produced may have an effect upon the change of the colour of the fat as influenced by the feed fed. Reed, Yamaguchi, Anderson, and Mendel (4), in studying the factors influencing the distribution and character of adipose tissue in the rat, found that approximately twice as much total fat (fatty acids) was deposited by rats fed a diet rich in fat (Crisco) as by animals that ate an equicaloric amount of a diet rich in cornstarch. Similar relatively increased fat storage was found with trials using mutton tallow and soy bean oil rations. Maw *et al.* (5), studying the effect of protein levels in the ration with stock of different ages during growth, show that there is no significant effect upon the chemical composition of the thigh muscle. There was, however, a wide difference in the fat content of the muscle as between the check stock and the fattened stock.

The present problem deals with the study of the effect of yellow corn and crude corn oil as sources of supplementary fat in a mixed cereal ration upon gains with varying lengths of feeding period, and the total percentage fat found in the drawn carcass.

MATERIALS AND METHODS

Stock

Range-grown Rhode Island Red cockerels approximately mature in body development were used. Six groups of 21 individuals were fed on each ration.

[1] Contribution from the Faculty of Agriculture of McGill University, Macdonald College, P.Q., Canada, with assistance from the Dominion Department of Agriculture, Ottawa, and the National Research Council, Ottawa, Canada. Macdonald College Journal Series No. 89. Presented before the Annual Meeting, Poultry Science Association, Madison, Wisconsin, August 13, 1937.

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[3] Formerly, Research Assistant, Department of Chemistry.

[4] Lecturer, Department of Poultry Husbandry.

Treatment

All birds were individually cooped and fed, live weights and feed consumed at 7-day intervals being recorded for a total feeding period of 21 days.

Six different rations were used. The basal ration was made up of 31 pounds of each cereal: ground whole wheat, oats, and barley, 6 pounds animal protein (made up on the basis of 7½ pounds beefmeal and 5 pounds powdered buttermilk) and 1 pound salt. The basal ration was number I. Ration number II had equal parts by weight of the four cereals: ground whole yellow corn, wheat, oats, and barley, to which were added the same protein supplement and salt. Rations III, IV, V and VI, were composed of the basal ration to which were added 2.5%, 5.0%, 7.5%, and 10.0% of crude corn oil respectively as a fat supplement. The range of total per cent fat in the six rations was from 2 6% in ration number II to 12.8% in ration number VI.

PROPORTION OF BASAL MIXTURE TO SUPPLEMENT

Rations	I	II	III	IV	V	VI
Basal mixture— lbs	100	76 75	97 5	95 0	92 5	90 0
Corn supplement—lbs		23 25				
Corn oil supplement—lbs.			2 5	5 0	7 5	10 0
	100	100 00	100 0	100 0	100 0	100 0

PERCENTAGE COMPOSITION OF THE RATIONS

Ration number	Moisture	Ash	Fat	Fibre	Protein	N-free extract
I	11 1	4 03	2 8	5 7	14 0	62 37
II	11 3	3 68	2 6	4 4	13 4	64 62
III	11 6	4 10	5 5	5 7	13 6	59 50
IV	11 2	3 90	7 0	5 5	13 7	58 70
V	10 8	3 46	10 4	5 1	12 8	57 44
VI	10 6	3 66	12 8	5 1	12 4	55 44

Feeding

Three full-feeds daily were given throughout the entire feeding period. The consistency of feed given was such as to pour freely from a pail, but with no free water when placed in the troughs. All feed weighed back at 7, 14, and 21 days was calculated on a dry feed basis.

Preparing Carcasses for Chemical Analysis

Following dressing, the carcasses were chilled for 24 hours, after which they were drawn in the regular fashion, recording weights of all parts. The abdominal fat was considered a part of the drawn carcass. The drawn carcass was then boned, separating the skin, white meat, dark meat, and abdominal fat as individual samples for fat analysis. The perimuscular fat of the breast and leg muscles was considered a part of these two respective areas.

Chemical Analysis

The method of analysis used was that described by Holcomb and Maw (6), with the modification of allowing the digestate to evaporate to a volume somewhat less than the volume of the bulb of the mojonnier extraction tube.

THE EFFECT OF LENGTH OF FEEDING PERIOD AND CORN AND FAT SUPPLEMENTS ON FATTENING GAINS

The experimental data obtained in these trials are given in Table. 1. The mean values for initial weight are given, as well as the gains and feed consumption on a 7-day feeding period basis with their totals and the gain-feed ratio. It is to be noted that the mean initial weights for the six groups were extremely uniform. The coefficient of variability for initial weight was 8.6%. The gain-feed ratios for the total 21-day period show

TABLE 1.—MEAN VALUES OF INITIAL WEIGHT, GAIN, AND FEED CONSUMPTION

Ration	Feeding periods			
	7 days	8–14 days	15–21 days	Total
I. Wheat-oats-barley				
Initial weight	2981.90			
Gain	152.61	104.28	153.57	410.47
Feed consumed	976.00	953.52	1010.76	2940.28
Gain per 100 grams feed				13.96
II. Corn-wheat-oats-barley				
Initial weight	2937.61			
Gain	144.52	151.19	101.42	397.14
Feed consumed	943.19	989.33	987.90	2920.42
Gain per 100 grams feed				13.59
III. Wheat-oats-barley + 2½% corn oil				
Initial weight	2969.04			
Gain	209.28	123.33	132.14	464.76
Feed consumed	1037.71	985.57	1013.95	3037.23
Gain per 100 grams feed				15.30
IV. Wheat-oats-barley + 5% corn oil				
Initial weight	2938.57			
Gain	160.47	139.28	116.66	416.42
Feed consumed	971.04	975.42	947.33	2893.80
Gain per 100 grams feed				14.39
V. Wheat-oats-barley + 7½% corn oil				
Initial weight	2908.33			
Gain	206.19	113.33	126.66	446.19
Feed consumed	996.66	961.90	954.00	2912.57
Gain per 100 grams feed				15.31
VI. Wheat-oats-barley + 10% corn oil				
Initial weight	2969.76			
Gain	160.23	141.42	129.04	430.71
Feed consumed	913.90	985.61	935.47	2835.00
Gain per 100 grams feed				15.19

slight differences, the rations supplemented by oil having slightly higher ratios of feed consumed to the gains made.

For the purpose of analysing the gains on the basis of variance, the 21 birds on each ration were randomized into three groups, fed for 7, 14, and 21 days. In Table 2, the analysis of gain is given on a basis of variance due to periods and rations within periods. This analysis shows the significant effect of the longer feeding periods on gain. There was no effect of the different rations on the gains made, the mean square between rations within periods being somewhat smaller than the mean square within rations. The coefficients of variability of gain for the 7-, 14-, and 21-day periods were 83.8%, 43.8%, and 40.3% respectively.

TABLE 2.—ANALYSIS OF GAINS

Source	D/F	S.S.	M.S.	½ $\log_e$	S.D.
Between periods	2	1,596,988 49	798,494.25	6.7952	
Between rations within periods	15	314,132 74	20,942.18	4,9748	
Within rations	108	2,540,846 43	23,526.35	5.0328	153.58
Total	125	4,451,967 66	z for periods = 1.7624		

It would appear that the gains made on a short-term feeding period are very greatly influenced by the initial reaction of the individual birds to the environmental and feeding differences of the fattening method. With the longer feeding periods, the birds made much more uniform gains.

In order to eliminate the effect of initial weight and feed consumption on gain, the observed gains have been corrected by regression. The analysis of the adjusted gains is given in Table 3. This analysis shows that even with the removal of the effect of these two variables no differences exist between the gains made by the birds on the different rations.

TABLE 3.—ANALYSIS OF ADJUSTED GAINS

Source	D/F	S.S..	M.S.	½ $\log_e$	S.D.
Between periods	2	11,394,802 52	5,697,401 26	7.7777	
Between rations within periods	15	196,932 02	13,128.80	4.7409	
Within rations	106	1,101,338 51	10,389.99	4.6188	101.93
Total	123	12,693,073.05			

. Corrected for regression of gain on initial weight b_1 = −0 0278431 and gain on feed consumption b_2 = 0.5056757.

RESULTS OF CHEMICAL ANALYSIS

Table 4 gives the percentage of fat found in the analysis of the carcasses of three birds (drawn at random) from the groups fed on the different rations. It can be seen that the percentage of fat in the different parts is quite uniform for all the rations except ration number II, which contained corn, wheat, oats, and barley. In this case the percentages are slightly

higher. The raw data show that individually the three birds of this group, used in the analysis, were above the level of the birds in the other rations. The gains made by these birds were but slightly greater, and the feed consumed slightly less, than the average for the twenty-one birds.

The variance analysis of the percentage of fat shows significant differences between the ration groups. As shown in Table 5, the z value obtained is 1.0691. This is greater than the highly significant point of z for $n_1 = 5$ and $n_2 = 10$ which is 0.6009. In Table 6 the observed mean

TABLE 4.—CHEMICAL ANALYSIS OF MEAT, SKIN AND ABDOMINAL FAT. PERCENTAGE FAT IN SAMPLE

(Average of three individuals for each ration)

Ration	Skin	Abdominal fat	White meat	Dark meat	Total meat
I	32.53	77.03	3.79	8.53	6.55
II	47.06	88.26	4.82	9 13	7.18
III	42.50	80.56	3.80	6 26	5.12
IV	35.60	77.80	3.53	6.21	5.03
V	39.20	81.66	3.97	7.40	5.86
VI	38.50	82.36	4.03	7.93	6.25

TABLE 5.—ANALYSIS OF VARIANCE. PERCENTAGE FAT IN DRAWN CARCASS

Source	D/F	S.S.*	M.S.	$\frac{1}{2}\log_e$	S.D.
Between treatments	5	147.803	29.561	1.6932	
Within treatments	10	34.840	3.484	.6241	1.866
Total	15	182.643		$z = 1.0691$	

* Sum of squares corrected for regression of percentage fat on initial weight $b_1 = -0\ 00316954$ and percentage fat on feed consumption $b_2 = 0.00243345$.

percentages of fat in the total carcass are given, together with the values obtained when corrected by regression. From the standard deviation of 1.866 the necessary difference for high significance between any pair of means is 4.6536. It can be seen in Table 6 that the birds fed ration II,

TABLE 6.—MEAN VALUES OF PERCENTAGE FAT IN CARCASS

Ration	No. of birds	Observed	Corrected by regression
I Wheat-oats-barley	3	10.25	10.39
II Corn-wheat-oats-barley	3	16.77	17.22
III Wheat-oats-barley + 2½% corn oil	3	11.44	10.66
IV Wheat-oats-barley + 5% corn oil	3	10.09	9.47
V Wheat-oats-barley + 7½% corn oil	3	11.26	11.17
VI Wheat-oats-barley + 10% corn oil	3	11.66	11.97

containing the cereal corn, had a significantly greater amount of fat than any of the other groups. The differences between the birds fed the other rations are slight and of no significance.

SUMMARY

No significant differences in gain were found between birds fed on a basal fattening ration of wheat, oats, and barley, and five lots fed on the same basal ration supplemented by the cereal corn and varying amounts of corn oil.

Greater gains were made with 14-day and 21-day feeding periods as compared to a 7-day feeding period. The gains made during the shorter period had a very high coefficient of variability.

From the chemical analysis of representative samples drawn from the various groups it was found that corn, when added to the fattening ration, increased the percentage fat in the body tissues, and that corn oil added in varying amounts to the same basal ration did not increase the percentage of fat.

ACKNOWLEDGMENT

The corn oil used in these trials was supplied through the courtesy of Canada Packers Limited, Montreal.

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BOOK REVIEW

ARMSTRONG, S. F. British Grasses and Their Employment in Agriculture. (Third Edition). Published by the Cambridge University Press. Macmillan Company of Canada, Limited. $5.00.

This revised and enlarged edition includes much of interest to the practical agriculturist as well as to the teacher of scientific agriculture and to those engaged in agricultural research. The material is divided into two main parts—first a botanical section and second an agricultural section. A unique feature is the inclusion of the index with the glossary.

The Botanical Section opens with a chapter on morphology, in which the grass plant is considered from the root to the seed. The second chapter deals with the physiology of the grasses. Next follows a grouping of the principal species according to habitat and this is followed by three keys based on vegetative, floral and seed characters. The botanical section is completed with descriptions of about one hundred species.

The Agricultural Section opens with a chapter on "Characters which determine the use and relative value of grass in agriculture"; next follows a discussion of commercial, indigenous and new strains. Sixty pages are devoted to a discussion of the economic uses of about thirty of the more important species. Such points as suitability for grazing or for hay, type of turf produced, palatability, whether a "top" or "bottom" type, and season of high production are discussed in some detail.

The remaining chapters of the agricultural section deal with grass production including establishment and management of new stands of grasses and improvement of poor stands, the advantages of mixtures as compared to pure cultures, soil preparation, methods of sowing, use of nurse crops, use of fertilizers on different species, effects of over- and under-grazing, haymaking, ensilage and artificial drying of grasses.

Throughout this book the author has been concise yet descriptions and discussions are complete. The clear style of writing makes the text easy to understand and a pleasure to read.

—T. STEVENSON.

SCIENTIFIC AGRICULTURE

Vol. XVIII NOVEMBER, 1937 No. 3

THE CHEMICAL NATURE OF SOME TYPICAL SOIL PROFILES OF SASKATCHEWAN, CANADA

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[Received for publication September 20, 1937]

The morphology of the more important soils found in the Province of Saskatchewan has been described by Joel (7) and in Saskatchewan Soil Survey Report No. 10 (15). Type profiles were described and discussed in some detail in the above publications, as was also the relationship of these soils to world soil groups.

The purpose of this paper is to present chemical data for typical profiles representing the main soil groups found in Saskatchewan. This paper is therefore supplemental to the above mentioned publication by Joel and the reader is referred to it for more detailed morphological descriptions of soil profiles as well as a more detailed discussion of the climatic and vegetational conditions found in Saskatchewan.

A sketch map of part of the Province (Figure 1) shows the location of the main soil zones and also gives the approximate location where the profiles discussed in this paper were obtained. The numbers given on the sketch map

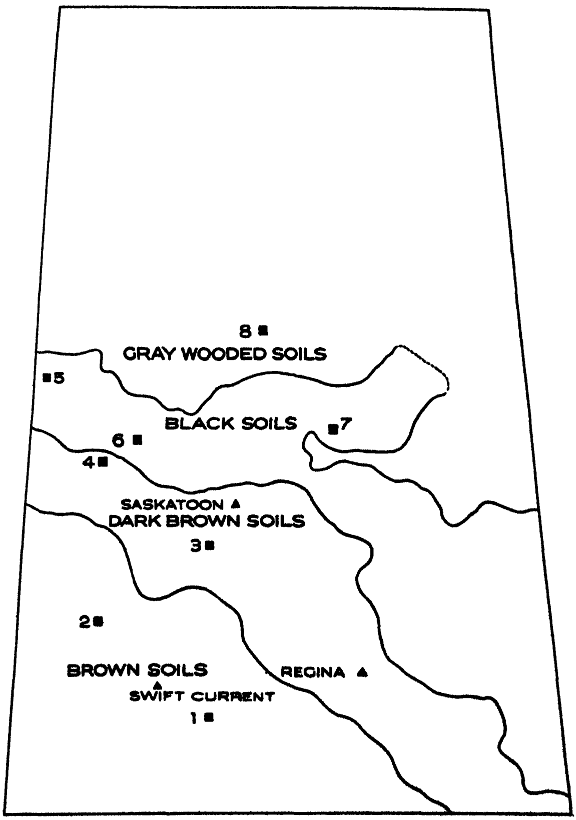

FIGURE 1. Showing main Soil Zones of Saskatchewan. The numbers refer to profile locations.

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correspond to the numbers used in designating the profiles throughout this paper.

DESCRIPTION OF PROFILES

The profiles as described below are placed in order of the main soil zones of the Province, beginning with the more arid brown soil zone of southwestern Saskatchewan and following in order to the dark brown and black soils of the central area and finally into the gray soil zone of the wooded area in the north and northeast part of the province.

Brown Soil Zone

*Profile No. 1. Brown loam on glacial till, Haverhill Series.**

Horizon	*Depth*	*Colour*	*Structure, etc.*
A_1	0″–3″	Gray-brown	Cloddy, faintly layered.
A_2	3″–7″	Brown	Top of long cloddy layer.
B_1	7″–11″	Brown	Long cloddy, somewhat compact.
B_2	11″–13″	Dark brown	Lower end of long cloddy.
B_3	13″–28″	Gray	Lime layer, some mottling with iron and lime splotches.

Profile No. 2. Brown loam on glacial till. Echo Series.

A_1	0″–3″	Dark brown	Thin platy, easily pulverized.
A_2	3″–7½″	Gray-brown	Cloddy; distinct platiness, easily pulverized.
A_3	7½″–9″	Light gray-brown (tends to ashy).	Thin platy (flakelike); easily pulverized.
B_1	9″–13″	Dark brown	Columnar, compact; breaks into hard angular fragments.
B_2	13″–18″	Brown	Like above but less compact.
B_3	18″–27″	Gray (brown)	Lime zone.
C	27″–42″	Gray	Calcareous parent till.

Dark Brown Soil Zone

Profile No. 3. Dark brown loam on glacial till. Weyburn Series.

A_1	0″–1″	Dark brown	Friable, soft granular, easily pulverized.
A_2	1″–4½″	Dark brown	Cloddy.
B_1	8½″–10″	Yellowish brown.	Same as above.
B_3	10″–13″	Pale grayish brown.	Lime layer.
C_1	2 ft.	Gray	Calcareous.

Profile No. 4. Dark brown loam on glacial till. Weyburn Series (Deeper phase).

A_1	0″–5″	Dark brown	Friable, granular, easily pulverized.
A_2	5″–11″	Brown	Long spike-like clods.
B_1	11″–17″	Dark brown.	Somewhat columnar and quite compact.
B_2	17″–24″	Gray-brown	Lime layer.

Black Soil Zone

Profile No. 5. Shallow black loam on glacial till. Oxbow Series.

A_1	0″–4″	Grayish black	Friable, granular.
A_2	4″–8″	Grayish black with brown tinge.	Granular to cloddy, friable.
B_1	8″–16″	Dark brown.	Long cloddy, slightly more compact than above.
B_2	16″–26″	Brown	Long cloddy.
B_3	26″–38″	Light yellowish gray	Lime layer.
C_1	38″–44″	Gray.	Calcareous till.

Profile No. 6. Black loam on lacustrine deposits. Blaine Lake Series.

A_1	0″–4½″	Gray black with brown tinge.	Platy, easily pulverized.
A_2	4½″–9″	Gray (ashy)	Platy (thick).
B_1	9″–18″	Dark coffee brown.	Columnar, breaking into hard angular fragments.
B_2	18″–24″	Gray.	Lime layer.

* Soil Series as named and described in Sask. Soil Survey Report No. 10 and former reports (15).

BLACK SOIL ZONE—*Concluded*

Profile No. 7. Deep black silt loam on lacustrine deposits. Melfort Series.

Horizon	*Depth*	*Colour*	*Structure, etc.*
A_1	0″–7″	Black to brown black	Soft granular, cloddy.
B_1	7″–18″	Dark gray brown.	Cloddy, friable.
B_2	18″–34″	Light gray brown.	Lime layer.
C_1	34″–42″	Gray, mottled.	Calcareous, structureless.
C_2	7 ft.	Gray	Calcareous lacustrine material.

FOREST GRAY SOIL ZONE

Profile No. 8. Gray loam on glacial till. Waitville Series.

A_0	½″	Organic debris	Structureless, easily pulverized.
A_1	½″–1½″	Dark fawn (slightly ashy).	Thinly plated, easily pulverized, gritty.
A_2	1½″–9½″	Ashy gray	Thinly plated, easily pulverized, gritty.
B_1	9½″–17″	Coffee brown	Compact, heavy in texture, breaks into angular fragments when dry.
B_2	17″–24″	Brown	Similar to above.
B_3(C)	24″–36″	Gray	Calcareous.

ANALYTICAL DATA[3]

Mineral constituents were determined from the Van Bemmelen-Hissink acid extraction method (17). Organic matter was determined by the Robinson McLean method (13). The hydrogen electrode was used to secure the pH values while carbon dioxide, sulphate, as well as other constituents were determined by standard analytical procedures. This data is included in Table 1.

TABLE 1.—ANALYTICAL DATA FOR PROFILES NO. 1 TO NO. 8. RESULTS EXPRESSED ON OVEN DRY BASIS

Horizon	Depth	Insol. Res.	Base Sol. Silica	Al_2O_3	Fe_2O_3	CaO	MgO	CO_2	pH	N	OM
					BROWN SOIL ZONE						
Profile No. 1. Brown loam, Haverhill Series.											
A_1	0″–3″	77.9	8.49	2.74	2 36	0.52	0.58	0.13	6.22	0.34	3.10
A_2	3″–7″	75.0	11.00	3.90	2 94	0.45	0.76	0.07	5.94	0.18	1.58
B_1	7″–11″	77.7	9.30	3.05	2.78	0.54	1.05	0.25	7.52	0.11	1.19
B_2	11″–13″	75.6	9.65	3.61	2.71	0.94	0.93	0.44	8.34	0.11	—
B_3	13″–28″	57 3	8.92	3 23	2.91	9.59	2.84	9 55	8.64	0.09	—
Profile No. 2. Brown loam. Echo Series.											
A_1	0″–3″	66.3	14 30	3 79	2.51	0 35	0.57	0.11	6.17	0.24	5.75
A_2	3″–7½″	76.1	8.85	3.41	2.13	0.18	0.48	0.00	6.20	0.11	3.19
A_3	7½″–9″	80.9	8.05	2 97	2.10	0.19	0.50	0.00	7.07	0.10	2.19
B_1	9″–13″	63.6	15.6	6 44	4.21	0.29	1.34	0.11	8.51	0.09	—
B_2	13″–18″	64 5	14.00	5.37	3.40	1.28	1.71	1.26	7.76	0.06	—
B_3	18″–27″	53.8	14.00	5.57	3.52	6 41	2.25	4.22	8.10	0.06	—
C	27″–36″	54 0	15.30	5.96	3.73	4.45	2.13	2.61	7.95	0.05	—
	36″–42″	72.8	8.05	3.12	2.70	3.14	2 04	3.02	8.16	0.03	—
					DARK BROWN SOIL ZONE						
Profile No. 3. Dark brown loam. Weyburn Series.											
A_1	0″–1″	Not analyzed.									
A_2	1″–4½″	73.9	10.35	3.20	2.74	0.76	0.66	0.18	7.23	0.25	4.25
B_1	4½″–8½″	73.7	11.42	4.16	2.97	0.68	0.69	0.08	6 85	0.12	2.11
B_2	8½″–10″	75.4	10.63	4.40	2.78	0.74	0.81	0.00	7.67	0.12	1.67
B_3	10″–13″	59.3	9.16	3.60	2.62	9.11	2.53	8.40	8.40	0.10	1.42
C_1	2 ft.	59.7	18.25	4.34	3.02	4.06	4.10	4.25	8.56	0.03	—
Profile No. 4. Dark brown loam. Weyburn Series (deeper phase)											
A_1	0″–5″	74.4	9.76	3.32	2.44	0.63	0.66	0.00	7.20	0.27	5.81
A_2	5″–11″	73.9	10.73	5.07	3.39	0.56	1.00	0.00	7.07	0.19	3.29
B_1	11″–17″	70.5	12.16	4.70	3.64	0.75	1.21	0.20	8.15	0.10	1.13
B_2	17″–24″	65.0	11.78	4.91	3.39	4.47	2.05	3.57	8.50	0.03	—

[3] The analytical data reported in the following tables are mainly from analyses carried out in connection with the Soil Survey of Saskatchewan, a co-operative enterprise undertaken by the Soils Department, University of Saskatchewan, with assistance from the Dominion and Provincial Departments of Agriculture.

TABLE 1.—ANALYTICAL DATA FOR PROFILES No. 1 to No. 8. RESULTS EXPRESSED ON OVEN DRY BASIS—*Concluded*

Horizon	Depth	Insol. Res.	Base Sol. Silica	Al_2O_3	Fe_2O_3	CaO	MgO	CO_2	pH	N	OM
				BLACK SOIL ZONE							
Profile No. 5.	*Shallow black loam.*			*Oxbow Series.*							
A_1	0"–4"	66.3	9.48	3.22	2.70	0.96	0.74	0.04	7.36	0.63	12.10
A_2	4"–8"	Not analyzed.									
B_1	8"–16"	73.1	8.90	3.91	3.16	0.62	0.80	0.00	6.43	0.29	5.26
B_2	16"–26"	78.0	9.15	3.86	3.14	0.35	0.99	0.00	7.31	0.10	3.17
B_3	26"–38"	64.5	8.92	3.75	2.91	6.44	1.79	4.20	8.27	0.06	0.92
C_1	38"–44"	67.2	9.80	3.95	3.15	4.72	1.90	3.57	8.49	0.04	—
Profile No. 6.	*Black loam.*		*Blaine Lake Series.*								
A_1	0"–4½"	68.9	9.47	3.81	2.73	0.76	1.48	0.00	—	0.50	9.95
A_2	4½"–9"	83.1	6.19	2.76	2.28	0.37	1.19	0.00	—	0.12	1.79
B_1	9"–18"	61.4	17.17	7.80	4.73	0.33	3.36	0.00	—	0.10	1.33
B_2	18"–24"	54.8	14.88	6.75	4.18	4.42	5.78	3.28	—	0.06	—
Profile No. 7.	*Deep black silt loam.*			*Melfort Series.*							
A_1	0"–7"	64.2	9.19	3.97	2.71	1.61	0.86	0.25	7.35	0.68	11.57
B	7"–18"	70.1	10.52	4.44	3.23	1.01	0.87	0.06	7.10	0.29	4.00
	18"–34"	66.3	7.95	3.07	2.36	7.68	1.86	6.48	8.55	0.06	0.88
C_1	34"–42"	53.6	13.57	6.85	3.13	7.23	1.68	5.40	8.60	0.06	—
	7 ft.	Not analyzed.									
				FOREST GRAY SOIL ZONE							
Profile No. 8.	*Gray loam.*	*Waitville Series.*									
				Total oxides							
A_0	0"–½"	Not analyzed.									
A_1	½"–1½"	91.1	2.65	2.82		0.28	0.37	0.00	6.90	0.08	—
B_1	9½"–17"	77.1	9.32	7.58		0.51	0.86	0.00	6.68	0.05	—
B_2	17"–24"	78.0	9.13	7.20		0.58	0.95	0.00	6.35	0.05	—
B_3	24"–36"	67.5	7.16	5.60		8.45	1.47	6.74	7.99	0.03	—
C	42"	62.1	10.3	7.26		6.42	3.22	6.05	8.24	0.03	—

Table 2 gives the exchangeable bases and the exchange capacity. Normal NH_4Ac (pH = 6.9) was used as the leaching solution for the removal of the exchangeable bases; for determination of total exchange capacity the soil was leached with neutral normal Ca $(Ac)_2$, with subsequent leaching of the Ca-soil with N/1 NH_4Ac to determine adsorbed Ca.

TABLE 2.—EXCHANGEABLE BASES. RESULTS EXPRESSED IN MILLIEQUIVALENTS PER 100 GRS. OF SOIL

Horizon	Depth	Ca	Mg	Na+K	Total	Total Exchange Capacity
			BROWN SOIL ZONE			
Profile No. 1.	*Brown loam.*	*Haverhill Series.*				
A_1	0"–3"	13.1	3.4	0.6	17.1	15.3
A_2	3"–7"	11.2	4.6	0.7	16.5	15.9
B_1	7"–11"	12.0	6.2	0.2	18.4	15.8
B_2	11"–13"	22.0	6.7	0.6	29.37	19.6
Profile No. 2.	*Brown loam.*	*Echo Series.*				
A_1	0"–3"	9.7	4.1	2.6	16.4	24.4
A_2	3"–7½"	4.2	2.8	2.5	9.6	14.0
A_3	7½"–9"	3.4	4.8	2.3	10.5	11.2
B_1	9"–13"	5.1	19.7	2.4	27.2	28.5

TABLE 2.—EXCHANGEABLE BASES. RESULTS EXPRESSED IN MILLIEQUIVALENTS PER 100 GRS. OF SOIL—*Concluded*

Horizon	Depth	Ca	Mg	Na+K	Total	Total Exchange Capacity
			DARK BROWN SOIL ZONE			
Profile No. 3.	*Dark Brown loam.*		*Weyburn Series.*			
A_1	0″–1″					
A_2	1″–4½″	18.8	1.5	2.2	22.5	19.5
B_1	4½″–8½″	16.2	2.4	2.9	21.5	18.2
B_2	8½″–10″	16.2	2.4	2.0	20.6	18.4
Profile No. 4.	*Dark brown loam.*		*Weyburn Series (Deeper phase)*			
A_1	0″–5″	14.6	5.1	1.5	21.2	20.2
A_2	5″–11″	11.1	7.6	0.5	19.2	19.8
B_1	11″–17″	10.8	13.6	1.5	25.9	23.8
			BLACK SOIL ZONE			
Profile No. 5.	*Shallow black loam.*		*Oxbow series.*			
A_1	0″–4″	25.9	8.8	2.9	37.6	35.2
A_2						
B_1	8″–16″	16.8	6.6	3.3	25.7	26.8
B_2	16″–28″	7.3	10.5	2.7	20.5	18.7
Profile No. 6.	*Black loam.*	*Blaine Lake Series.*				
A_1	0″–4½″	22.2	8.9	3.4	34.6	34.2
A_2	4½″–9″	7.8	5.4	1.5	14.8	13.2
B_1	9″–18″	5.2	23.4	1.8	30.6	29.4
Profile No. 7.	*Deep black silt loam.*		*Melfort Series.*			
A_1	0″–7″	49.5	9.8	–	59.3	59.9
B	7″–18″	27.3	6 9	–	34.2	33.6
			FOREST GRAY SOIL ZONE			
Profile No. 8.	*Gray loam.*	*Waitville Series.*				
A^2	1½″–9½″	11.0	4.0	–	15.0	13 4
B_1	9½″–17″	5.1	0.6	–	5.7	9.2
B_2	17″–24″	11.8	5.3	–	17.1	13.3

SOLUBLE CONSTITUENTS

Two profiles were examined for soluble salts and horizons having a considerable concentration were analyzed to provide information as to the nature of the soluble constituents. These results are given in Table. 3.

TABLE 3.—SOLUBLE CONSTITUENTS OF PROFILES 2 AND 5

Horizon	Depth	HCO_3	Cl	SO_4	Ca	Mg	Na (by diff.)	Total salts
Profile No. 2.	*Brown loam.*	*Echo Series*						
A_1	0″–3″							0.09
A_2	3″–7½″							
A_3	7½″–9″							0.15
B_1	9″–13″							
B_2	13″–18″							0.20
B_3	18″–27″	0.07	0 05	2.52	0.69	0.22	0.18	3.71
C	27″–36″	0.04	0.06	1.48	0.26	0.20	0.04	2.08
	36″–42″	0.03	0 02	0.42	0.05	0.06	0.02	0.59
Profile No. 5.	*Black loam.*	*Oxbow Series.*						
A_1	0″–4″	Not analyzed.						
A_2	4″–8″							
B_1	8″–16″							0.04
	16″–26″							0.11
B_2	26″–38″	0.04	Nil	1.03	0.23	0.10	0.10	1.54
C_1	38″–44″	0.04	Nil	0.63	0.11	0.09	0.07	0.96

DISCUSSION OF ANALYTICAL DATA

General

The effective moisture increases as one passes in a northerly or easterly direction from the southwest corner of the Province of Saskatchewan. In the northerly direction this condition is a result of lower average temperature, rather than from an increase in precipitation. In the easterly direction, however, an increase in precipitation does occur.

The geographical positions of the soil zones as indicated in Figure 1 reflect this climatic and resultant vegetational influence. The lime layer becomes progressively deeper on the average from the brown soils of the open plains to the gray wooded zone. Nitrogen and organic matter increase until the gray wooded soils are encountered. The relationship of climate and vegetation to the soil zone is more fully discussed in Soil Survey Report No. 10 (15).

Profile Development and Eluviation

An examination of the profile descriptions and of the analytical data given in Table 1 gives an indication of the degree of eluviation which has occurred. Profiles Nos. 2, 6, and 8 show distinct differences between the A and B horizons. The other profiles of the group are not notably differentiated. In the former group the development of eluvial and illuvial horizons has progressed to the point where these soils may be definitely described as leached soils. Removal of colloidal materials from the surface layers has occurred and possibly some destruction of the clay complex has been associated with such movement. A comparison of the iron and alumina oxide content of the more contrasting profiles is of interest in this connection. In Table 4 the comparative amount of these constituents in each horizon of Profiles Nos. 2, 3, 5, 6, and 8 is given. By taking the combined sesquioxides found in the B_1 horizon as 100, the comparative amount in each horizon is readily seen. The slight variation indicated for horizons of profiles No. 3 and 5 is in harmony with other analytical data to be found in Table 1 and also with the descriptions of horizons in these profiles. Profiles Nos. 2, 6 and 8, on the other hand, as indicated previously, show sharp contrasts between the A and B horizons, not only in the sesquioxides but in base soluble silica and also in the degree of removal of the bases, calcium and magnesium.

TABLE 4.—COMPARISONS OF PERCENTAGES OF SESQUIOXIDES IN VARIOUS SOIL HORIZONS OF PROFILES 2, 3, 5, 6, AND 8

Horizon	Profile 2	Profile 3	Profile 5	Profile 6	Profile 8
A_1	63		90	58	
A_2	53	85		41	50
A_3	49				
B_1	100	100	100	100	100
B_2	84	100	96.5	90	95
B_3	90	95	95.5		83
C	93	98	98		96

Exchangeable Bases

A study of the exchangeable bases and total exchange capacity of these profiles provides some further information of interest in relationship to the character of the soils. The results are given in Table 2. The

influence of the presence of increasing amounts of organic matter on base exchange capacity is indicated by the comparison between the total exchange capacities of Profiles Nos. 1, 3, and 5. The texture in each case is loam, but the organic matter content is respectively 3.10, 4.25 and 12.1% while the base exchange capacity is 15.3, 19.5, and 35.2 milliequivalents per 100 grams.

The dominant exchangeable ions are calcium and magnesium. In no case are there large proportions of the alkalies (Na and K) present, and they are more or less uniform in quantity throughout the profile. The presence of exchangeable hydrogen is indicated in the A horizons of Profile No. 2 and in the B horizon of Profile No. 8 by the fact that the total exchange capacity is in excess of the sum of exchangeable bases. The pH values of these soils as given in Table 1 indicate slight acidity only.

A study of the ratio of exchangeable Ca to Mg is of interest in relationship to the degree of eluviation in these profiles. In Table 5 the ratio of Ca/Mg is given for the various horizons of the soils.

TABLE 5. RATIO OF EXCHANGEABLE CA TO MG

Horizon	Profile numbers							
	1	2	3	4	5	6	7	8
A_1	3 8	2.35	12.0	2 86	2.92	2.5	5.05	2.75
A_2		2 5			2.54	1.45		
A_3		0.71						
B_1	2.6	0.26	6.75	1.45	0.70	0.22	4.0	8.5
B_2	1.9		6.75	0.795				2.2

The ratio of exchangeable Ca to Mg is from 2.5 to 12. in the surface horizons. This value is less in the lower horizons of all profiles except in No. 8. In profiles No. 2 and 6 this ratio reaches the low value of 0.26 and 0.22 in the B_1 horizons; and it is also to be noted that the ratios of 2.35 and 2.5 for the surface horizons of these soils were the lowest of any in the group. Soils No. 2 and 6, as has already been pointed out, are distinctly eluviated types and some further discussion is to be given in a later section regarding their chemical nature and possible genesis. Profiles Nos. 4 and 5 have slightly higher exchangeable Mg than Ca in their B horizons. They are not notably differentiated nor are profiles Nos. 1 and 7 which have higher exchangeable calcium throughout. Profile No. 8, described as a gray loam of the forest region, shows strong eluviation. Exchangeable Ca exceeds Mg throughout this profile. Some further discussion is to be given this and other chemical conditions of the profile.

Soluble Salts

Determination of the kind of soluble salts in many soils in the Province of Saskatchewan have lead the authors to conclude that sulphates of calcium, magnesium and sodium are the most common. Calcium and magnesium usually exceed sodium. The presence of chlorides in any amount beyond traces is not usual and the occurrence of sodium carbonate is relatively uncommon. The soils of this study were examined for the presence of concentrations of salts in the profile. The lower horizons of Profiles Nos. 2 and 5 showed considerable concentrations, and the constituent salts were determined in such horizons. The results are given

in Table 3. It may be noted that the concentrations occur in the lower B horizons and also that the salts are predominantly sulphates of Ca, Mg and Na, the latter being present in the smallest quantities.

Reaction

Extremely alkaline or extremely acid soils are uncommon in Saskatchewan. Out of many tests conducted on surface samples and on horizons of profiles few have been more acid than pH 6.0. On the other hand, while most samples show reactions on the alkaline side of neutrality, comparatively few are more alkaline than pH 8.5. The lime layer usually has a reaction of about this value.

The surface layers of Profiles No. 1 and 2 are slightly acid; the lower layers, however, are alkaline, as may be expected in the presence of free lime. Both profiles were obtained from the more arid Brown Soil Zone. Profile No. 8, although from the more moist wooded zone, does not indicate the degree of acidity commonly associated with such soils. Many samples of similar soils have been tested with similar results. The gray soils of the wooded area of this Province so far encountered are only slightly acid in reaction.

DISCUSSION OF CHEMICAL DATA IN RELATION TO MORPHOLOGY AND GENESIS

Several publications (7, 15) have dealt with the occurrence, morphological descriptions and possible genesis of the soils of Saskatchewan. The relationship of these soils to world groups has been suggested, although it was recognized that more chemical and other laboratory data were desirable before a complete parallel should be drawn between Saskatchewan soils and the "solonetz", chernozem" or "podsolic" soils originally described by European workers. It is possible that the use of this terminology is somewhat misleading, since some of the chemical features commonly ascribed to solonetzic and podsolic soils are absent in Saskatchewan soils of similar morphological character. Nevertheless, the conceptions of climatic relationships and morphological character in the classification of soils was of great value to the progress of soil surveys in this area as well as in other parts of the world.

Discrepancies between morphological descriptions and chemical data have been observed by many investigators, so that a new emphasis is likely to be placed on laboratory work in an attempt to interpret more completely field observations. The advantages which would result from the accumulation of definite quantitative criteria in relationship to soil character are many. Neutralization, to some extent at least, of personal error in recording profile descriptions, is one of them. It must be remarked, however, that field observation is of paramount importance, since the accuracy of laboratory results depends upon how well the samples obtained represent the various horizons of a given soil profile.

Solonetzic Types

Soils having the morphology of solonetz and solodized solonetz types are common in Saskatchewan. Attention has been drawn to solodized soils occurring in some areas as eroded complexes (7, 15) where the A horizons are more or less completely removed in irregular patches, leaving a shallow pit-like micro-relief. The latter have been locally termed

"burn-out" or "blow-out" soils in the provinces of Saskatchewan and Alberta. The topography of such areas is usually level to gently undulating.

Profiles Nos. 2 and 6 are typical both morphologically and chemically of leached solonetzic types found in Saskatchewan. However, the element sodium does not appear to have played an important role in their profile development. Calcium and magnesium are the dominant exchangeable ions, the latter being in excess of calcium in the B horizon. Kelley (8) has drawn attention to apparently similar conditions in solonetz-like soils of California. Ellis and Caldwell (4) have described such soils occurring in Manitoba, and have used the term, "magnesium solonetz", in describing them. Rost (14) also has reported on somewhat similar soils.

Kellogg (9) has recently reviewed the theory advanced by Gedroiz regarding the role of sodium in the genesis of solonetz soils. However, it appears that there are areas of soils on this continent as well as in Europe (5, 16) which, while appearing to be morphologically typical of the solonetz, have not the chemical character usually associated with these soils, at least in so far as the presence of excess exchangeable sodium in the profile is concerned.

The presence of considerable exchangeable magnesium might lead to the inference that the influence of magnesium is similar to that of sodium. However, there appears to be little evidence at the moment that the magnesium ion would act as a deflocculator of clay colloids. Sushko (15), while concluding that the degree of solodization is roughly comparative to the accumulation of exchangeable magnesium in the lower solum, does not associate the genesis of the profile with this condition. In Saskatchewan increasing ratios of magnesium to calcium in the B_1 horizon of solodized soils appear to be associated with a greater degree of downward movement of material in the profile. This is illustrated in Table 5 in the low calcium magnesium ratios of the strongly eluviated profiles Nos. 2 and 6, already discussed in a previous section.

The presence of soluble salts in the lower horizons is a fairly common feature in Saskatchewan soils, particularly in solonetzic types. The salts present in the leached profile No. 2, while higher in concentration, are similar in constitution to those found in profile No. 5. The relatively high percentage of calcium and magnesium minimizes the possibility that considerable sodium exchangeable may have existed in a solonchak stage. The analysies of soluble salts reported here are quite typical for soils of this Province. It would therefore be difficult to explain the leaching effects on the basis of the dispersive influence of sodium in earlier stages of profile development.

Norton (12) and Bray (1), in studying the Prairie soils of Illinois, consider that clay pan formation is largely due to the translocation of fine clay particles from eluvial to illuvial horizons. Bray further consideres the fine clay colloid (probably 0.1μ or less in particle size) may undergo movement when only slightly unsaturated. Jenny and Smith (6) consider the presence of electrolytes, carbonates and certain sols to be factors influencing the retention of such colloidal material in the B horizon. A prominent morphological feature in solidized soils in Saskatchewan is their compact, impervious, highly colloidal B horizon, which is underlain by a lime accumulation zone and a zone of soluble salts ($CaSO_4$, $MgSO_4$.

Na_2SO_4, etc. See Table 3). The A horizon is almost structureless, is quite friable and has suffered moderate leaching.

Slight unsaturation is common in the A horizon of solonetzic types in Saskatchewan, and the clay material, especially in the upper B horizon, appears to exist in a highly dispersed state. Flocculation is induced in the lower B horizon through the presence of calcium carbonate and various soluble salts. The ease of dispersion which appears to characterize the clay of these soils is possibly related to the type of parent material from which tney are derived. Edmunds (3) and Joel (7) have suggested that the occurrence of eroded solonetzic types of soil in Saskatchewan is correlated with the presence of non-calcareous shales which underlie the till at shallow depths in many such areas. It is possible that downward movement of finely divided and easily dispersed clay, such as might originate from these shales, accounts in part at least for the highly colloidal B layer of solonetzic types in Saskatchewan.

X-ray diffraction studies (2) further bear out the probability that the nature of the clay fraction of such soils is influenced by the mineralogical make-up of the clay fraction of the parent materials. The clay fraction of such soils requires further study before the pedogenic processes connected with their formation can be satisfactorily explained.

Podsolic Types

Profile No. 8 is typical for soils found over a large area of the wooded zone in northern Saskatchewan. The A and B horizons have the morphology generally described for soils of the podsol group. The chemical data given in Table 1 show that considerable weathering and movement of material has occurred in the profile. This is substantiated in the data giving exchangeable bases and exchange capacity (Table 2) and further illustrated by Table 4.

However, in contrast to the chemical nature usually ascribed to such soils, there is the presence of free lime at shallow depth, the slight acidity of the profile, and the fact that calcium remains the dominant exchangeable ion throughout the profile. The presence of lime in the subsoil does not preclude the possibility of the surface becoming highly leached, but dependent upon the type of natural vegetation would affect the degree to which such leaching might progress. The podsolic types in Saskatchewan commonly occur under a forest vegetation of deciduous trees, mainly poplar species. This type of vegetation would undoubtedly tend to return a greater amount of calcium and other bases to the surface in leaf fall than the conifers, and this may account for the fact that these soils are rarely markedly acid in reaction.

It is suggested by Leahey (10), in discussing the podsolic soils of Alberta, that conifers may have in the past been more prominent in the vegetation of such areas than is now the case. Moss (11), however, has pointed out that in Saskatchewan podsolic types occur both under pure deciduous as well as under mixed deciduous and evergreen stands.

Podsolic types in Saskatchewan occur on a variety of parent materials, including glacial lacustrine and sandy alluvial deposits. The lighter textured soils are, of course, most strongly leached, and also the most acid in reaction.

A forthcoming publication by Moss (11) will deal in greater detail with the morphology and chemical composition of podsolic types of Saskatchewan.

SUMMARY

Chemical data including exchangeable bases, and for certain profiles soluble salts, are given for profiles representative of the main soil groups in Saskatchewan.

Two types of leached profiles are represented. These are the leached soils of the grassland areas, which have the morphology of solonetzic soils, and the leached soils of the wooded areas, which are podsolic.

A relatively small proportion of exchangeable sodium is found in the solonetzic types. The presence of an excess of exchangeable magnesium over calcium in the B horizon appears to be typical of solonetzic soils in the area but this element is not considered to be solely responsible for the dispersion and subsequent movement of colloidal material within the profile. The nature of the clay minerals of the parent material is considered to be of importance in relationship to the formation of the compact, impervious, highly dispersed clay-pan-like B horizon of such soils.

Podsolic types are found under deciduous forest vegetation. Although they have been strongly leached, their present reaction is only slightly acidic, and calcium remains the dominant exchangeable ion throughout the profile.

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"ALKALI" SOILS IN SASKATCHEWAN[1]

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There is a large area of saline soils in the Province of Saskatchewan. The soluble salts present in such soils are variable both in kind and amount and also in their distribution throughout the soil profile. According to computations made by MacFarlane (1), 1391 square miles or roughly 900,000 acres, are shown on the soil survey map (4) as alkali soil areas. This does not include numerous small sloughs or flats which could not be indicated in the scale of mapping used in the survey, nor does it indicate the area affected within the boundaries of a soil series such as the Yorkton (4) with its associated localized saline areas.

The greater acreage of saline soils is to be found in the more arid brown and dark brown soil zones (4) of the southwestern part of the Province. Snow white crusts of salts at the margin of lakes or on dry lake beds and alluvial flats are a common sight in the southwest. In general this type of land is of low value. Where the salinity is not too high, fair native grass is to be found and such land is useful for pasture. However, both the quantity and the quality of the feed grown on such areas is poor, as a rule. It may be remarked that certain saline lakes of this area have proven valuable as sources of sodium sulphate.

In the eastern part of the province there is also a considerable acreage of saline soils. This area in the main lies within the more moist black soil zone (4) and is more or less coincident with the soils of the Yorkton series. The presence of soluble salts is not so readily recognized here since climatic conditions promote their distribution in the soil profile, and surface crusting is somewhat less common. On reference to the soil map (4) it is noted that the largest continuous area of saline soil in the province is in this eastern part, namely, in the ancient lake-bed and drainage channels of the Quill Lakes. Saline soils are less common in the northern areas, but are occasionally encountered even in the gray soil zone of the northern forest region. Saline peats have been found as far north as the National Park north of the city of Prince Albert and in other localities within this zone.

In addition to the soils which have soluble salts in concentration at the surface, there are the types which have horizons of salt accumulation in the subsoil. This condition is not readily perceivable and the large amounts of soluble salts present at comparatively shallow depths are often only revealed by chemical analysis. Salinized horizons of the subsoil are characteristic of such soil series as the Echo and Elstow (4) but are also present in certain phases of other series.

It appears unlikely that any but a small proportion of the soluble salts found in Saskatchewan soils originate through weathering which has occurred since glaciation.

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

[2] Professor of Soils, University of Saskatchewan.

COMPOSITION OF SALTS FOUND IN SASKATCHEWAN SOILS

The sulphates of calcium, magnesium and sodium are the predominant salts present in saline soils of this province. Chlorides are present in some samples, but it is common to find only traces of the chloride ion present in making an analysis. In many cases calcium sulphate is present in the greatest amounts and sodium sulphate the least. Observations indicate that the toxicity of the salts increases with increasing percentages of sodium, and especially so with sodium chloride. Analyses reported by Shutt and Smith (3) on samples obtained from near Maple Creek, Sask., indicate sulphates of calcium, magnesium and sodium as the compounds present. Sodium sulphate was the chief component present in two sets of samples obtained from land which had been under irrigation some years.

Sodium carbonate (black alkali) soils are of infrequent occurrence in Saskatchewan. A few patches occur near the town of Wilkie and a profile analysis from one of these will be presented later in this paper.

The following description and analysis is of samples obtained near Langenburg in eastern Saskatchewan. This soil may be considered as a salinized phase of the Yorkton series.

A description of the three horizons of the profile analyzed is as follows:

0 – 8″ Very dark gray, soft cloddy friable loam, specks of lime or salts. Moderate effervescence.

8 – 13″ Similar to above, slightly more compact, and with less organic matter.

13 – 22″ Compact yellowish clay loam, mottled and becoming bluish gray at lower depths.

Impeded drainage is evident in this profile. The topography was flat and surface drainage rather poor at the point where the sample was obtained. There was a good cover of grass and shrubs, and a few yards away the land was under cultivation. According to the farmer who was cultivating the nearby field, the grain crops did not suffer except in drier seasons.

TABLE 1.—SOLUBLE CONSTITUENTS OF LANGENBURG PROFILE*

Depths	0 – 8″	8 – 13″	13 – 22″
pH	8.5	8.2	8.8
Ca	0.304	Not determined	0.602
Mg	0.266	Not determined	0.158
Na (by diff.)	0.190	Not determined	0.142
SO_4	1.818	Not determined	2.138
Cl	0.014	Not determined	0.007
CO_3	Nil	Not determined	Nil
HCO_3	0.055	Not determined	0.024
Total salts	2.643	2.058 (by ign. of residue)	3.071

* Analyses reported in this paper are by the conventional 1 : 5 dilution with shaking for one-half hour.

The predominance of calcium sulphate in the above analysis may be noted. This salt increases with depth, while magnesium and sodium tend to decrease. This condition, however, would be subject to variation with

fluctuations in moisture. The amount of chloride ion present is quite small and there was no carbonate ion indicated.

A surface sample from a small local area on the University farm at Saskatoon gave the following results on analysis:

Depth	0 - 6″
pH	6.7
Ca	0.123
Mg	0.186
Na (by diff.)	0.248
SO_4	1.236
Cl	0.103
CO_3	Nil
HCO_3	0.017
Total salts	1.913

This sample was obtained from the edge of a patch at a point in rows of barley judged to be the limit of tolerance for that crop. Nearby rows of wheat and alfalfa indicated a limit of tolerance of 1.023 and 1.167% total salts. The texture of this soil was clay loam.

Sulphates are predominant in this analysis as in the Langenburg profile, but sodium sulphate is present in larger quantities than either calcium or magnesium sulphate in this case. There is also somewhat more chloride ion than was found in the Langenburg soil. Chlorides do not usually make up a large proportion of the soluble salts present in soils of this province; in fact, as stated above, the chloride ion is generally present only in traces. However, a few samples have been found in which the salts present were mostly chlorides.

Sodium Carbonate Soils

A sample of soil containing sodium carbonate was brought to this department by a farm owner who had noted several small patches of barren soil with a surface of unusually dark-coloured, oily appearance. The patches were being cultivated and sown along with the remainder of the field and according to the owner had never produced any vegetation whatsoever. A patch examined by the writer was found to be within an area of undulating glacial loam (Weyburn series) and was about 40 feet in diameter. The topography was flat but not depressional. The edge of the patch was very sharply defined, the crop of oats being normal in appearance within one foot of the barren area. The surface was dark brown to black in colour and of a rather greasy appearance.

The soil profile was examined within the barren patch and the profile description is as follows:

0 – 4″ Dark coloured surface soil cultivated. A very thin surface crust was in evidence. Moderate effervescence.

4 – 8″ Reddish brown, slight platiness, rather compact, slight effervescence.

8 – 16″ Brown, small cloddy with faint platiness, moderate effervescence.

16 – 24″ Gray brown, mottled, strong effervescence. The parent material appeared to be till of medium texture.

Samples were obtained from this profile and also a sample of surface soil at a distance of 10 feet from the edge of the patch where crop growth appeared quite normal.

The analytical results on the above samples are given in Table 2.

TABLE 2.—SOLUBLE CONSTITUENTS OF SODIUM CARBONATE SOIL

Depth	0 - 4″	4 - 8″	8 - 16″	16 - 24″	Sample taken outside barren area 0 - 6″
pH	10 06	9 90	8 76	8 46	8 42
Ca	0 016	0 009	0 013	0 280	—
Mg	0 006	0 003	0 013	0 052	—
Na (by diff.)	0 220	0 111	0 077	0 044	—
SO_4	0 058	0 040	0 115	0 872	Trace
Cl	0 068	0 017	0 031	0 024	Trace
CO_3	0 181	0 100	0 002	0 000	—
HCO_3	0 023	0 000	0 055	0 027	0 04
Total salts	0 572	0 280	0 306	1 299	0 07

From the above analysis it may be observed that sodium carbonate is present in considerable quantities in the first and second horizons. In the 8–16″ depth, the carbonate radical is present in traces only and is entirely absent in the lower depth. The pH of the profile horizons substantiates the analysis, inasmuch as the results show a decline from the surface horizon of 10.06 to pH 8.46 in the lower horizon. It is obvious that there is excess calcium sulphate in the lower horizon which would prevent the formation of soluble carbonates. The pH of 8.46, while fairly alkaline, is not beyond the alkalinity which may be due to calcium carbonate (5). The surface 8″ of this profile is apparently a typical "black alkali" soil, but the subsoil is of the "white alkali" kind. Sodium chloride and sodium carbonate decrease with depth, while calcium and magnesium sulphates increase.

There is probably very little movement of soluble constituents within this profile due to the rather impermeable nature of the 4–8″ horizon. However, if the excess salts were to leach to the lower horizons, dispersion and downward movement of clay constituents would no doubt be intensified. It may be noted that the sodium carbonate on reaching the subsoil horizons would be converted into sodium sulphate and therefore a marked reduction in the alkalinity of the profile in terms of pH would follow. Solonetzic soils are common in Saskatchewan and it is possible that the commonly described process of formation has been effective in their development. On the other hand, sodium carbonate soils are rarely found in this province, exchangeable sodium is present in only small amounts in soils of solonetzic morphology (2), and sodium salts are generally present in smaller proportion in saline soils than either calcium or magnesium. The latter facts would indicate the possibility that other theories than the sodium theory may be necessary to explain the formation of soils of solonetzic morphology in this region.

Salinized Subsoil Horizons

Salinized horizons of the subsoil are frequently encountered in the soils of Saskatchewan, especially in those of a solonetzic type of morphology. Normal profiles of such soils as those of the Melfort, Regina and Waitville series (4) are free of such layers but they are occasionally present in the Haverhill, Weyburn and Oxbow (4).

The following profile description is that of an Echo type (4), a soil of solonetz-like morphology. A patchy erosion of the A horizon of this soil results in the shallow pit-like micro-relief locally termed "burn-out" land.

Depth	*pH*	*Description of horizons*
0 - 3″	6.17	Dark brown, thin, platy, easily pulverized loam.
3 - 7½″	6.20	Gray brown, cloddy, distinctly platy, easily pulverized.
7½ - 9″	7.07	Light gray, flake-like, easily pulverized.
9 - 13″	8.51	Dark brown, columnar, hard and compact, heavy.
13 - 16″	7.76	Brown, similar to above but less compact.
18 - 27″	8.10	Grayish brown, lime zone.
27 - 36″	7.95	Gray calcareous till, gypsum and other salts.
36″+	8.16	Gray calcareous till; parent material.

The horizons above 18″ contained less than 0.2% total soluble salts, so the constituent ions were not determined. The results of determinations on the remaining horizons are given in Table 3.

TABLE 3.—SOLUBLE CONSTITUENTS IN LOWER HORIZONS OF A SOLONETZIC TYPE

Depth	18 - 27″	27 - 36″	36″+
pH	8.10	7.95	8.16
Ca	0.668	0.260	0.054
Mg	0.216	0.196	0.059
Na (by diff.)	0.180	0 040	0.020
SO_4	2.520	1.480	0 417
Cl	0 053	0.064	0.017
CO_3	Nil	Trace	Trace
HCO_3	0.071	0.045	0.027
Total salts	3.708	2 075	0.594

The percentage of soluble salts increased sharply from 0.20% in the 13″ to 18″ horizon to 3.708% in the 18″ to 27″. Below 36″ there was a drop to 0.59%. Calcium is in excess throughout the salinized layers and the salts are again predominantly sulphates. There is no indication of sodium carbonate in any horizon of the profile.

Whether or not such shallow salinized layers affect plant growth is not certain. The plant roots would no doubt penetrate to greater depths, but it is unlikely that available moisture would exist beyond the depths where salt accumulation is encountered. The compact, impermeable nature of the upper B horizons of such soils is probably more detrimental to the growth of plants than is the salinity of the lower layers.

A more detailed and intensive investigation of saline soils is at present under way[3]. It is hoped that from the results of such investigations more definite information on the limit of tolerance of different crops for the various types of salts encountered may be obtained. It is significant of the importance of this problem that more samples are submitted to this Department for examination because of "alkali" than for any other condition. In a large percentage of cases the cause of unsatisfactory production is not suspected by the farmers or others submitting such samples. The recent progress in the development of irrigation projects in this Province makes the study of saline soils and related problems of additional importance.

[3] With financial assistance for Soil Research under the Prairie Farm Rehabilitation Act.

SUMMARY

Saline soils are of widespread occurrence in the Province of Saskatchewan. The soluble salts present are commonly sulphates of calcium, magnesium and sodium, the chlorides being relatively uncommon. Sodium carbonate is of infrequent occurrence in the soils of the area.

The analyses indicate that calcium and magnesium predominate over sodium in the saline soils examined. The analysis of the sodium carbonate soil indicates that sodium carbonate may in some cases be confined to surface layers. In this profile only the upper eight inches contained this salt. Salinized subsoil layers are of frequent occurrence in the Province of Saskatchewan.

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SOME OBSERVATIONS ON SOIL SURVEY WORK IN SASKATCHEWAN[1]

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INTRODUCTION

This paper constitutes a brief review of soil survey work in Saskatchewan together with a discussion of some of the problems involved and suggestions regarding future activities. In order to appraise the work accomplished to date, it is advisable to outline the origin of the survey. In 1920 the provincial government, at the request of numerous residents of southwestern Saskatchewan, held a Better Farming Conference at Swift Current. This conference was attended by technical agriculturists and practical farmers, who met to discuss the problems arising from several years of drought and soil drifting. As recommended by the Conference, a Royal Commission was appointed to investigate the condition of agriculture in the area, and from a recommendation of the latter body the Saskatchewan Soil Survey was created.

In view of the present activities in soil survey and land utilization work, it is worthwhile noting some of the specific recommendations of the Commission as quoted from the report (2).

"1. That a reconnaissance soil survey of Saskatchewan be undertaken to outline the various soil areas and classify them as to their suitability for grain growing and stock raising; and that the reconnaissance survey be followed by a more complete agricultural survey in order to render the investigational work of the Agricultural College and Experimental Farms more effective.

"2. That areas unsuitable for grain growing be converted into community pastures.

"3. That rural municipalities be given power to prevent the cultivation of sandy lands which blow to such an extent as to be detrimental to adjoining farm lands.

"4. That experiments be undertaken with a view to determining the varieties of grasses and the methods most suitable for rendering such areas fit for grazing purposes."

The Commissioners also discussed the scope of the proposed survey, and their conclusions were as follows: "The soil survey is not to be regarded as a relief measure from which immediate results will accrue. It is not a cure-all of difficulties, and in itself is not an end but rather a means to an end. But it *will* assist in anticipating future difficulties, in putting agriculture on a permanent basis and in guiding investigational work."

"The type of survey deemed suitable to Saskatchewan conditions is one intermediate in scale between a reconnaissance and a detailed survey." It was pointed out that a detailed survey is adapted to regions of intensive agriculture where the high cost per acre is justified, and to less fertile but

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

[2] Soil Specialist under the Prairie Farm Rehabilitation Act (P.F.R.A.).

more humid regions where the use of soil amendments is profitable. On the other hand, a superficial reconnaissance survey does not provide sufficient detail to be of full benefit to the farmer and investigator.

"The soil survey should be conducted with the University as the central point of activity and the work should begin in the southwest and be extended throughout the province."

The Commission also stressed the necessity of controlling soil drifting. Reference to the need for reclaiming badly drifted soils is also given in the first soil survey report (3) which covered part of the sandy area extending from Caron to Mortlach, a district which is at the present time one of the serious problem areas of the Province.

SOIL SURVEY WORK PRIOR TO 1936

The Saskatchewan soil survey was directed at first by Prof. Roy Hansen, later by Prof. A. H. Joel, and at the present time by Dr. J. Mitchell. The survey progressed slowly but steadily until 1929, when the Central Experimental Farm co-operated in the work, almost perished in 1932, due to lack of nourishment, and in 1936 grew again in size and vigor through the assistance of the P.F.R.A. The latter project, like the soil survey, came into existence as a result of drought, soil drifting and agricultural depression.

The first seven survey reports (3) cover relatively small areas mapped approximately to a detailed reconnaissance scale. Reports Nos. 8 and 9, covering portions of southwestern Saskatchewan, were mapped on a broader scale. All areas covered in the first nine reports are included in Report No. 10, published in 1936 as the *Reconnaissance Soil Survey of Saskatchewan* (3). The development of soil science since the beginning of the survey is reflected in the later reports by the prominence given to genetic factors of soil formation and the use of the soil profile as the basis for soil classification. The broader scale of mapping was adopted in order to speed up the work. This was made necessary by the large area to be covered, the demand for soil information, and the fact that only one or two field parties were available.

The publication of the reconnaissance map and report marks the virtual completion of the first stage of soil investigations in Saskatchewan. It is true that the report does not cover the whole of the settled area of the province, and that the detail is not sufficient to classify individual farms. Nevertheless, the report deals with all the extensive agricultural soils in use at the present time and provides an excellent basis for future agricultural policies and investigations. The combined information supplied by the map and report may be said to summarize our present knowledge of Saskatchewan soils.

PRESENT PROBLEMS OF THE SOIL SURVEY

In 1936 the Saskatchewan Soil Survey carried out three distinct types of survey work. These were: detailed reconnaissance surveys of wind eroded soils at Mortlach, Cadillac and Hodgville; a more detailed survey of the Eastend, Val Marie and Teo Lake irrigation projects; and reconnaissance mapping in the unsurveyed areas of northern Saskatchewan.

At the present time the first mentioned type of survey is receiving most attention and the work has been broadened to include the mapping of other "problem" soils. These include all types of light textured soils, all severely drifting types, poorly drained soils, soils associated with rough topography and excessive stoniness, and those having inherent undesirable characteristics, such as the extreme solonetz or "blow-out" types. The work has been arranged to cover certain rural municipalities and in this way the survey data will be of greater value to governmental departments which are accustomed to dealing with individual municipalities. The present survey is also designed to fit in with the land utilization studies conducted by the Department of Farm Management.

It will be evident that most of the surveys now in progress are being conducted in areas already covered by the reconnaissance survey. An important problem therefore is that of selecting a suitable scale of mapping, which on the one hand will justify a re-survey of certain areas, and on the other, will not be too slow and costly. In the case of the surveys of selected municipalities, the object is to obtain information sufficient to arrive at the potential agricultural value of each quarter section. In particular the aim is to map closely the boundaries between arable and non-arable soils. The land is being covered by a combination of foot and car traverses, the better types of soil being covered more quickly as they do not constitute a serious problem as do the poorer soils. The field data is placed on township sheets on a scale of 2 inches = 1 mile. The completed work will probably be shown on municipal maps on a scale of 1 inch = 1 mile.

A number of other problems have to be settled during the course of the field work. It is obvious that in the reconnaissance survey many features could not be shown on the map, and a number of different though related factors had to be grouped together. In the more detailed surveys now in progress it becomes necessary to decide how far it is advisable to differentiate minor soil and topographic features. The mapping of topography is a case in point. With the exception of soil texture no single factor is more important than that of topography. Relatively slight changes in slope profoundly influence profile characters, moisture efficiency and the amount of land which may be cultivated. Nevertheless it is not feasible to separate every variation in topography, since it is often difficult to decide where the boundary lines should be placed. The problem is complicated by the fact that in a glaciated region such as Saskatchewan a great deal of the surface is characterized by various phases of rolling topography. For example, a smooth 4% slope extending over a whole quarter section represents very different conditions of soil and agricultural use from the same slope occurring as a series of ridges and depressions. In the former case the topography can be mapped by simply measuring the slope, while in the latter the frequency or number of "rolls" per half mile must also be taken into consideration. It is expected that the various topographic phases now being mapped may eventually be grouped according to percentage slope and frequency, so that such a term as "gently rolling" may be designated by measurable units.

Much of the present survey work is carried on in areas affected by wind erosion, where the original soil profiles have been altered by soil drifting. In some cases the soils are buried under drifted material, while

in others all or part of the profile has been removed. Frequently both conditions occur in close proximity and the area has to be designated as one in which both accumulation and removal have taken place. Variations in the degree of accumulation or removal also occur and it is frequently impossible to map all the phases of soil drifting which may be found on a single quarter section.

The degree of wind erosion is shown in the map by the use of symbols which indicate the amount of damage suffered by the soil, and, in some measure, the loss of fertility. The latter factor is difficult to estimate, since it depends both upon the severity of erosion and the type of parent material. Wind erosion on Regina heavy clay, while it represents a serious loss of potential fertility, may still leave the soil reasonably productive. A similar degree of erosion on Hatton fine sandy loam may destroy the present fertility of the soil. In mapping wind eroded soils consideration must also be given to the composition of the drifted material, particularly where it forms the present surface of cultivated lands. Previous studies (1) have shown that the drift from sandy soils and from glacial loams and clay loams is lighter in texture and lower in potential fertility than the original soil. In the case of the heavy lacustrine types the soil and drifted material are practically identical. It will be seen that wind erosion is far more destructive on the first mentioned soil types, and that the loss of fertility is correspondingly greater.

Another problem of the present surveys is concerned with the mapping of soil complexes. In certain areas frequent variations in parent materials, local climatic factors, topography and drainage result in the occurrence of intricate mixtures of soil series and types. These mixed soils occur so frequently and over such small areas that they cannot be shown separately on the map. It is therefore necessary to group several series or types together and in such cases each soil boundary is an arbitrary line and the final designation of the soils within the boundaries is a compromise.

In discussing the survey work now in progress it should be mentioned that the surveys of irrigation projects are being continued this year. These surveys are being made at the request of the Water Development Committee, P.F.R.A. They are designed, in conjunction with topographic data supplied by the engineers, to provide a classification of each parcel of land according to its potential value for irrigation. In addition to the ordinary field work, numerous soil samples are taken, in order to secure data on the soluble salt content, permeability, texture, structure and other soil features. The location of the samples and of important physical features is obtained by pacing and compass bearings. The Brunton compass is used for this purpose and also to measure slopes in the other surveys. This instrument has proved very useful as it combines reasonable accuracy with ease and speed of operation. The field work is performed by foot traverses and the mapping is done on a scale of 4 or 5 inches = 1 mile. The greater detail used in this type of survey is justified by the high cost of irrigation projects.

Further activity in the survey of northern Saskatchewan has been temporarily postponed owing to pressure of work from the other survey projects. The amount of unsurveyed agricultural land and the areas covered to date are listed in Table I.

TABLE 1.—THE RELATION OF SOIL SURVEYS TO LAND AREAS IN SASKATCHEWAN

Total area of Saskatchewan	155,764,480 acres
Area covered by reconnaissance soil survey	60,181,600 "
Area of settled land not covered by soil surveys	8,640,000 "
Area covered by detailed reconnaissance surveys	276,360 "
Area covered by irrigation surveys	10,000 "
Area under cultivation, 1936	29,871,550 "

CONCLUSIONS

A review of the present activities in soil survey, land classification and reclamation work in southwestern Saskatchewan suggests that some of the recommendations of the Better Farming Commission of 1920 are now being put into practice. It therefore seems logical at this point to consider the next stage of soil investigations in this province.

It is important that the reconnaissance survey of the northern areas be continued, in order to complete the inventory of the soils of Saskatchewan. Furthermore, the gray soil (podzol) region is associated with a number of important soil problems, and it is desirable that these be investigated in order to assist in the improvement of agricultural conditions in the newer settlements.

It will ultimately be necessary to decide how much of the province is to be re-surveyed in conjunction with land utilization studies. In this connection it may be pointed out that problems of soil management and land use are not confined to the present drought area. Wind erosion, for example, is becoming a serious problem on many of the lighter soils of the dark brown and black soil zones.

Regardless of the type of survey adopted or the purpose for which it is undertaken, one of the objectives of future projects should be the securing of additional fundamental knowledge of representative soil types. This involves considerable laboratory work in addition to the field studies. The use of laboratory data to support field observations becomes increasingly important as greater detail of mapping is required, and this is particularly true in the surveys of irrigation projects.

If the soil survey may be regarded as the basis for future agricultural policies and research, it may be said that the surveys already completed and those now in progress open the way to many lines of investigation. The soil survey, in addition to supplying soil and land utilization data, may be expected to assist in the solution of problems in agronomy, plant pathology, entomology, and other agricultural sciences.

The foregoing statement suggests the desirability of using the soil survey data to anticipate future problems, in so far as that is possible. It may be hoped that survey activities will not be confined to the poorest soils. The survey of these soils is made necessary by the present condition of agriculture, but ultimately it is more important to study the better soils and to assist in keeping them fertile and productive, since they are far more valuable than the poorer types. In fact it may be questioned whether the very poor soils warrant the time and cost required to make a fairly detailed survey, outside of the value of separating these soils from the better types. Such a survey can only be justified if it results in the adoption of a proper land use programme. In the long run soil conservation will pay better dividends than soil reclamation.

Finally, the future progress of soil science in this province requires that the work be established on a more permanent basis than has prevailed up to the present. The value of soil surveys and related investigations has been amply demonstrated in this and other provinces. The general recognition now accorded this fact would seem to warrant soil science being placed upon an equal footing with the other sciences which have become so vital a part of Canadian agriculture.

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KIND, POSITION, AND TOXICITY OF ALKALI SALTS IN CERTAIN ALBERTA IRRIGATED SOILS, AND TOLERANCE OF CROPS FOR THESE SALTS[1]

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INTRODUCTION

The introduction of irrigation in many additional localities by the water development activities of the Prairie Farms Rehabilitation Act has caused an increased interest in soil alkali, as accumulations of alkali salts often take place where moisture conditions of the soil are changed by the artificial application of water. For this reason any studies of aklali soils that have been made in western Canada may be useful to those who may meet this problem as irrigation is extended. Realizing this, it was thought advisable to present some alkali experiments conducted by the Canadian Pacific Railway some years ago.

The investigations reported here were inaugurated by the late Don. H. Bark, then Chief of the Irrigation Investigation Division, Agricultural Industry Branch, Department of Natural Resources, Canadian Pacific Railway, in connection with the Company's development of the Eastern Irrigation District in the vicinity of Brooks, Alberta. The work was conducted by the author under Mr. Bark's direction during the years 1917, 1918 and 1919. The data accumulated were reported to the Railway Company in three annual reports that have not been published. Recently the farmers of the Eastern Irrigation District organized themselves under the Irrigation Districts Act of Alberta, and the interests of the Canadian Pacific Railway in the land and water project were transferred to the district. Since this transfer, the Manager of the C.P.R. Department of Natural Resources has authorized the author to publish or otherwise use the data.

While these investigations were concluded 18 years ago, the data secured still may have application to our present day problems. It is not the purpose of this paper to present all of the data at this time but to make a comparatively brief report of those parts that seem to be of principal value. If it is deemed advisable later a more detailed analysis may be made.

MATERIAL AND METHODS

It is the purpose here to report:

1. The kind and amount of water soluble salts found at various soil depths and the change in position of the salts with irrigation.
2. The tolerance of crops for salts in the soils studied.
3. The ameliorating action of gypsum on other sulphates.

Soil samples were secured for analysis in several localities chiefly in the Tilley District, and it is the Tilley soils that are reported here as more detailed work was done with these soils than with any on the project. The soils in this district are mostly blow-out soils typical of the Tilley East

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, June 28–30, 1937.

[2] Assistant Superintendent.

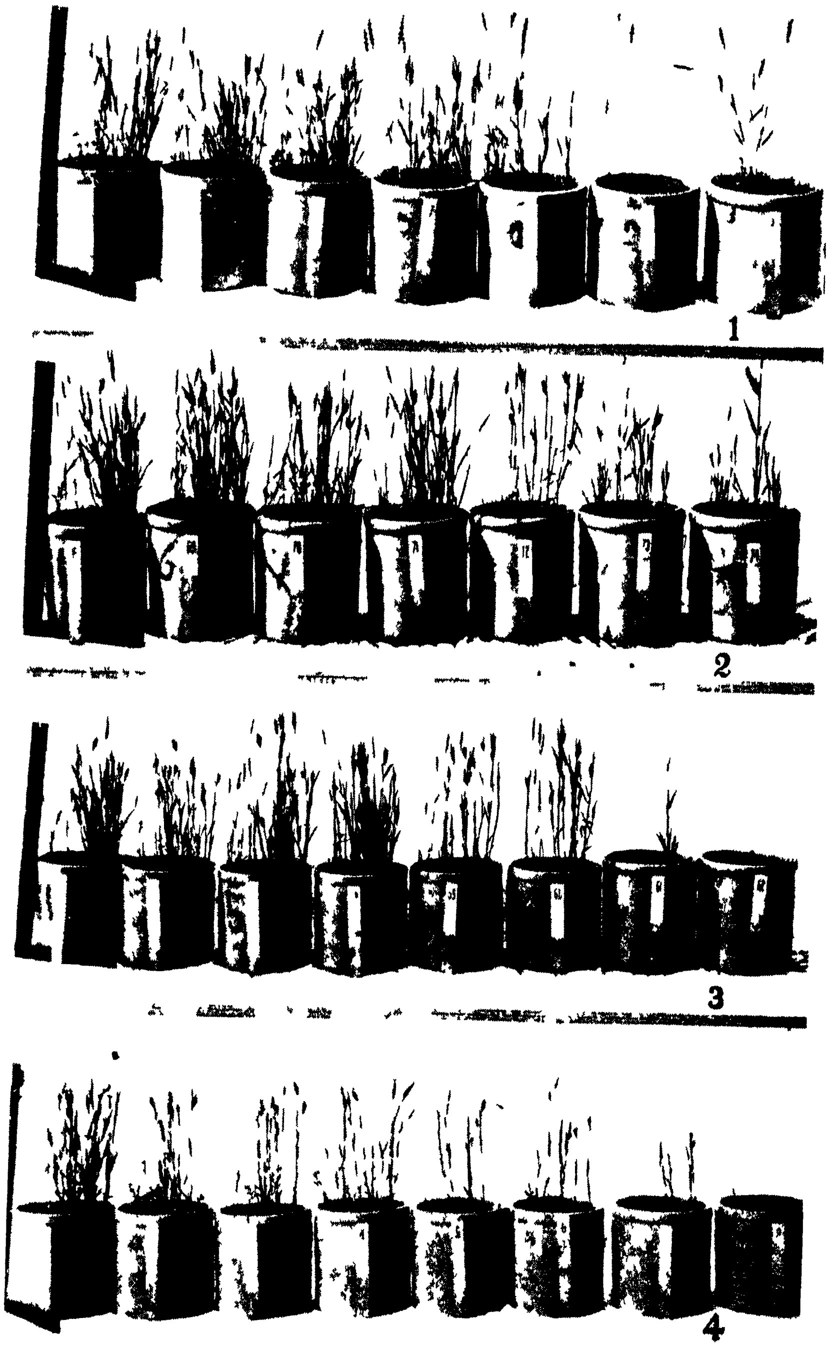

PLATE I. Wheat and barley grown on clay loam with different amounts of salts added to the soil. Reading from left to right the percentages of salts in the soil contained in the pots were: FIGURE 1.—Na_2SO_4—Nil, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50. FIGURE 2.—$MgSO_4$—Nil, 0.30, 0.60, 0.90, 1.20, 1.50, 1.80. FIGURE 3.—Na_2CO_3—Nil, 0.025, 0.10, 0.20, 0.40, 0.60, 0.80, 1.00. FIGURE 4.—$NaCl$—Nil, 0.025, 0.10, 0.20, 0.40, 0.60, 0.80, 1.00. Wheat on the left half and barley on the right half of each pot.

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PLATE II.—Wheat and barley grown on clay loam with different amounts of salts added to the soil. Reading from left to right the percentages of salts in the soil contained in the pots were: FIGURE 5.—$CaSO_4$—(Nil) (5.0) (15.0) (5.0) (15.0) (5.0) (15.0). FIGURE 6.—Mixture of Na_2SO_4 and $MgSO_4$. The first amounts are Na_2SO_4. (Nil) (0.25-0.25) (0.25-0.75) (0.25-1.25) (0.75-0.25) (0.75-0.75) (0.75-1.25) (1.25-0.25) (1.25-0.75) (1.25-1.25). FIGURE 7.—Mixtures of Na_2SO_4 and NaCl. First amounts are Na_2SO_4. (Nil) (0.25-0.025) (0.25-0.20) (0.25-0.50) (0.75-0.025) (0.75-0.20) (0.75-0.50) (1.25-0.025) (1.25-0.20) (1.25-0.50). FIGURE 8.—Ameliorating action of $CaSO_4$. ($MgSO_4$-0.90) ($MgSO_4$-1.20) (Na_2SO_4-0.75-$MgSO_4$-0.75) (Na_2SO_4-1.25-$MgSO_4$-1.25) (Na_2SO_4-0.75-$MgSO_4$-0.75-$CaSO_4$-2.0) (Na_2CO_4-1.25-$MgSO_4$-1.25-$CaSO_4$-2.0) (Na_2SO_4-0.75) (Na_2SO_4-1.25)

area and some are relatively impervious to water. In determining the kind and position of salts the soil samples were secured in foot sections to a depth of six feet and determinations were made of the individual ions of the salts found in the water extraction except that no separation was made of the sodium and potassium.

The investigations regarding the tolerance of crops for salts were conducted either by placing soils of known salts content into three-gallon pots and growing crops on these soils, or by mixing salts with soils of low salts content and growing the crops on these soils in pots. Determinations were made also of the salts in field soils where alkali accumulations had occurred. In these field investigations, borings were made in the crop where no alkali injury was apparent, at the edge of the alkali spots where crops showed decided injury, and just at the edge of the areas where growth was entirely inhibited.

RESULTS

Kinds of Salts

The principal water-soluble salts found in all of the silt and clay soils and a few of the sandy soils were Na_2SO_4 and $MgSO_4$, with considerable quantities of $CaSO_4$ A few sandy soils contained appreciable amounts of Na_2CO_3 or $NaHCO_3$, but there was very little chloride in any of the soil investigated. As much as 1% of the Na_2SO_4 or $MgSO_4$ was found in some layers of the virgin soils, and in some instances the combined amount of these salts was almost 2% In some of the soils there was about an equal amount of sodium and magnesium sulphate, while in some, magnesium sulphate predominated and in others there was more sodium than magnesium.

In determining the total soluble salts by evaporation of the water extraction, 4% of total water-soluble salts were found in a number of samples Usually, however, where these high concentrations were present in the virgin soil, about from $\frac{1}{3}$ to more than $\frac{1}{2}$ of the salt in the water extraction was $CaSO_4$

Positions of Salts in Soil

In the virgin, difficult permeable, silt soils the maximum salts concentrations were usually found in the third, fourth, or fifth foot, more frequently in the fourth foot. In readily permeable silt soils, the highest concentrations were found most frequently in the fifth foot, while in sandy soils the sixth foot usually contained more salts than did the soils nearer the surface. Where the soils were irrigated, there was a movement of salts downward as the irrigation water soaked to greater depths than the rainfall had been able to penetrate This loss of salts out of the top six feet of soil with two years of irrigation is shown graphically in Figures 1 and 2 and the amount, and kind of salts present in each foot of soil is presented in Table 1.

The amount and position of salts in three virgin soils is indicated in Figure 3, and the kinds and amounts of these salts are recorded in Table 2.

Tolerance of Crops for Salts

Where pure salts were added to a fertile soil practically free of alkali salts the germination of wheat and barley was slightly depressed with the addition of 0.5% of $NaSO_4$, 0.4% to 0 5% of NaCl, and 0.3% to 0.4% of Na_2CO_3. $MgSO_4$ seemed to have no depressing effect on the germination

TABLE 1.—CHANGE IN WATER SOLUBLE SALTS IN FIELD SOILS IN TWO YEARS

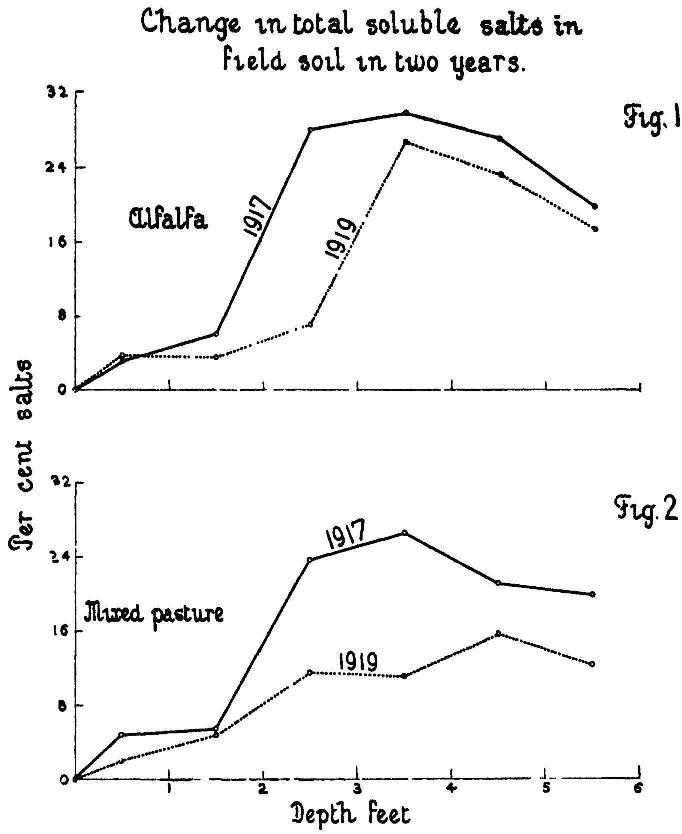
Depth, feet	Ions							Combinations									
	Ca	Mg	CO_3	HCO_3	Cl	SO_4	NN*	T.S.S.†	$CaCO_3$	$Ca(HCO_3)_2$	$CaSO_4$	$Mg(HCO_3)_2$	$MgSO_4$	$NaHCO_3$	NaCl	Na_2SO_4	$NaNO_3$
								Alfalfa field, 1917									
1st	0.03	0.03		0.19	0.003	0.22	0.003	0.33		0.11		0.09		0.04	0.005	0.04	0.02
2nd	.07	.03		.12	.001	.31	.0009	.61		.16	0.09		0.17		.002	.16	.006
3rd	.49	.10		.07	.007	1.82	.0006	2.81		.09	1.60		.51		.01	.45	.004
4th	.49	.13		.06	.009	1.96	.0007	3.00		.08	1.61		.63		.01	.51	.004
5th	.39	.12		.05	.01	1.79	.0005	2.73		.06	1.29		.57		.02	.67	.003
6th	.27	.08		.05	.007	1.28	.0005	1.98		.06	.86		.40		.01	.56	.004
								Alfalfa field, 1919									
1st	.04			.07	.004			.38		.06					.006		
2nd	.04	.01		.06	.005	.07		.36		.08	.06		.05		.008		
3rd	.08	.03		.04	.008	.36		.71		.06	.22		.15		.01	.15	
4th	.48	.09		.03	.007	1.66		2.68		.05	1.59		.42		.01	.29	
5th	.37	.09		.03	.006	1.46		2.33		.05	1.23		.43		.01	.37	
6th	.22	.07		.04	.01	1.14		1.75		.05	.71		.36		.02	.53	
								Mixed pasture, 1917									
1st	.05	.02		.19	.003	.03	.002	.47		.21		.04	.04		.005		.01
2nd	.06	.02	.02	.13	.004	.17	.002	.53	.03	.17	.03		.10		.007	.11	.01
3rd	.31	.13	.008	.07	.009	1.48	.0007	2.37	.01	.09	.99		.63		.01	.44	.004
4th	.45	.09	Trace	.07	.01	1.67	.001	2.64	Trace	.09	1.47		.45		.02	.42	.008
5th	.31	.08	Trace	.07	.01	1.31	.001	2.11	Trace	.09	.96		.38		.02	.50	.009
6th	.29	.07		.06	.01	1.24	.001	1.98		.08	.91		.34		.02	.39	.008
								Mixed pasture, 1919									
1st	.03	.009		.09	Trace	Trace		.19									
2nd	.07	.02		.07	Trace	.27		.47									
3rd	.17	.05		.05	Trace	.71		1.14		.07	.63		.25		Trace	.04	
4th	.14	.04		.04	.005	.68		1.10		.05	.45		.22		.008	.29	
5th	.21	.06		.04	.01	1.00		1.56		.05	.69		.31		.02	.40	
6th	.13	.05		.04	.008	.95		1.23		.05	.42		.25		.01	.68	

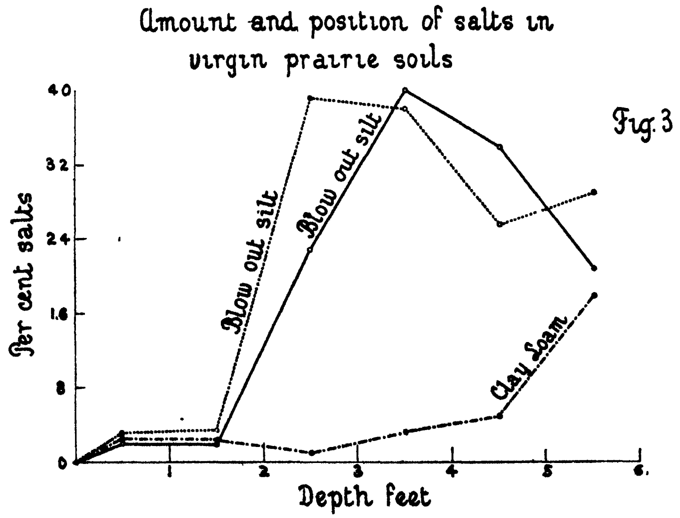
*Nitric nitrogen. †Total soluble salts.

TABLE 2.—WATER SOLUBLE SALTS IN TOP SIX FEET OF SOIL, TILLEY—RESULTS EXPRESSED AS PER CENT

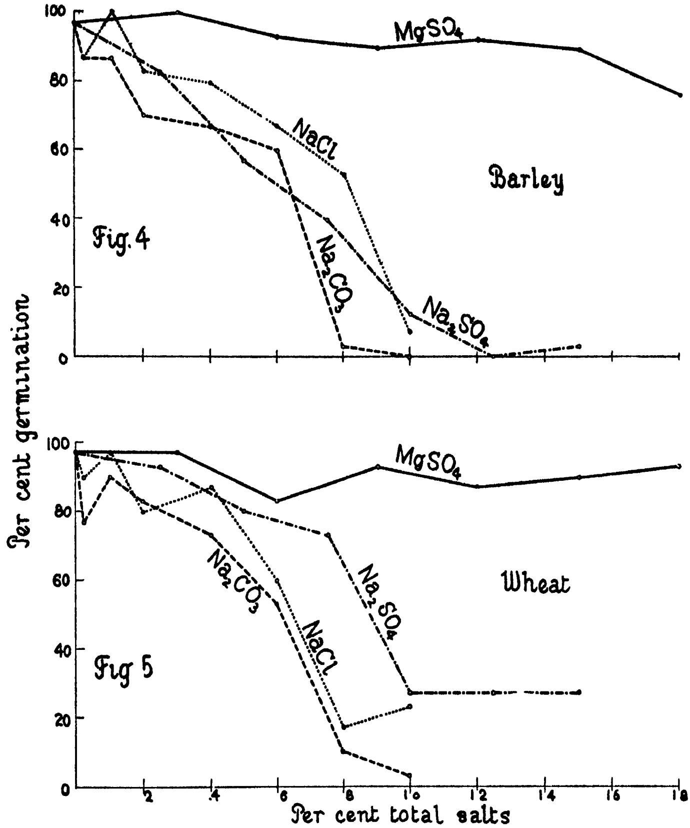
Depth, feet	Ions							Combinations									
	Ca	Mg	CO_3	HCO_3	Cl	SO_4	NN*	T.S.S.**	$CaCO_3$	$Ca(HCO_3)_2$	$CaSO_4$	$Mg(HCO_3)_2$	$MgSO_4$	$NaHCO_3$	NaCl	Na_2SO_4	$NaNO_3$
Blow-out silt																	
1st	0.02	0.009		0 09		0.01	0.002	0.20		0.07		0.04	0.01			0.002	0.01
2nd	.01	.007	0.008	.10	.001	.03	.0005	.19	0 01	.07		.03		0.05	0.002	.04	.003
3rd	.42	.08		.05	.01	1.47	.0003	2.30		.06	1.36		.38		.02	.31	.002
4th	'.70	.12		.04	.02	2.54	0003	4.01		.05	2.33		.61		.04	.78	.002
5th	.47	.08		.04	.01	2.09	0004	3.36		.05	1.57		.39		.02	1.02	.002
6th	.20	.11		.03	.02	.13	.0006	2.12		.04	.65		.55		.04	1.13	.004
Blow-out Silt																	
1st	.02	.01	.008	.11	.001	.03	.0003	.31	.01	.07		.06		.001	.002	.02	.02
2nd	.05	.02		.08	.009	.15	.0008	.33		.11	.09		.10		.01	.02	.005
3rd	.72	.16		.05	.03	2.57	.0006	3.93		.06	2.38		.78		.05	.41	.004
4th	.49	.19		.04	.03	2.42	.0006	3 80		.05	1 62		.92		.05	.84	.004
5th	.22	.14		.05	.03	1.66	.0008	2 56		07	.68		.67		.05	1.00	.005
6th	.18	.15		.05	.05	1.89	.001	2.92		.07	.57		.75		.07	1.38	.009
Clay loam																	
1st	.03	.01		.12	.004	.01	.004	.26		.14		.02	.01		.007		.02
2nd	.05	.009		09	.001	.06	.008	.24		.12	.05		.03		.002		.005
3rd	.02	.009		.10	.001	.03	.0007	.11		.09		.03	.02		.002	.02	.004
4th	.07	.01		.10	.002	.14	.0005	.33		.13	.12		.05		.004	.03	.003
5th	.06	.02		.08	.007	.27	.0003	.47		.11	.10		.10		.01	.18	.002
6th	.35	.06		.07	.009	1.18	.0004	1.77		.77	1 12		.30		.01	.24	.002

*Nitric nitrogen. †Total soluble salts.

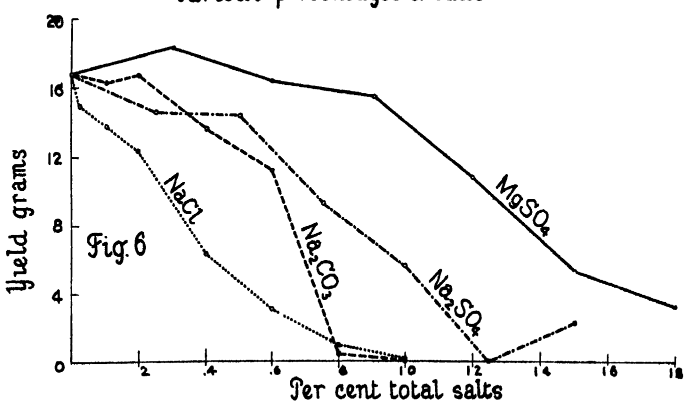

Change in total soluble salts in
field soil in two years.
Fig. 1
Alfalfa
1917
1919
Per cent salts
Fig. 2
1917
Mixed pasture
1919
Depth feet


Amount and position of salts in
virgin prairie soils
Fig. 3
Blow out silt
Blow out silt
Clay Loam
Per cent salts
Depth feet

Germination of grain in soils containing various percentages of salts.



Yield of barley in soils containing various percentages of salts.



of wheat or barley when added to form a concentration of as high as 1.8%. Growth of the crops after emergence seemed to have been slightly influenced by about 0.75% to 1% of NaSo$_4$, 1% to 1.5% of $MgSO_4$, 0.3% to 0.4% of Na_2CO_3 or 0.1% to 0.2% of NaCl. $CaSO_4$ used alone had no apparent influence on germination and growth up to the maximum concentration used, which was 25% of the weight of the soil. This test with $CaSO_4$ was made in each of the years of 1918 and 1919 and in none of the individual pots was there any deleterious influence noted from the addition of gypsum to the soil. These results are in agreement with field experience on gypsum soils of the west where soils high in $CaSO_4$ are good agricultural soils.

Where mixtures of salts were used the addition of Na_2CO_3 or NaCl to a soil containing $NaSO_4$ did not appear to injure the crop unless enough of one of these salts was added so that it alone would cause injury indicating that the toxicity of these salts was not added to that of $NaSO_4$. The same condition seemed to prevail in a mixture of Na_2CO_3 and NaCl but not in a mixture of $NaSO_4$ and $MgSO_4$, although the harmfulness of a mixture of these two sulphates did not seem to be equal to the sum of the toxicity of each salt. For example, if the lethal point for Na_2SO_4 was 1% and for $MgSO_4$ was 1.5% then for a mixture of equal parts of the two it should

TABLE 3.—GERMINATION AND YIELD OF BARLEY ON SOIL CONTAINING VARYING AMOUNTS OF SALTS

Kind of salts	Per cent salt	Per cent germination	No. of plants	Grain straw, grams
Na_2SO_4	0	97	8	16.76
	.25	83	8	14.60
	.50	57	6	14.38
	.75	40	4	9.18
	1.00	13	1	5.55
	1.25	0	0	0
	1.50	3	0	2.17
$MgSO_4$	0	97	8	16.76
	.30	100	10	18.33
	.60	93	9	16.40
	.90	90	9	15.42
	1.20	93	9	10.68
	1.50	90	8	5.23
	1.80	76	7	3.20
Na_2CO_3	0	97	8	16.76
	.025	87	9	15.08
	.10	87	9	16.30
	.20	70	7	16.65
	.40	67	6	13.63
	.60	60	5	11.05
	.80	3	0	.37
	1.00	0	0	0
NaCl	0	97	8	16.76
	.025	87	9	14.98
	.10	100	10	13.75
	:20	83	8	12.33
	.40	80	8	6.35
	.60	67	6	3.00
	.80	53	4	.93
	1.00	7	1	.07

have been 1.25% if the toxic action of the two were added to each other. In the tests, however, it required 1.5% of the mixed salts to give the same harmful action as 1% of Na_2SO_4 or 1.5% of $MgSO_4$.

Crops were injured by a much lower percentage of salts as shown by analysis of alkali soils than where similar mixtures of pure salts were added to fertile soils. In field alkali soils it appeared that 0.7% to 1.2% of a mixture of approximately equal parts of sodium and magnesium sulphates was as injurious in a silt-loam as 1.5% to 1.7% of these salts added to a fertile soil of similar texture. There was a good growth of western rye grass in the presence of a mixture of 1.26% of sodium and magnesium sulphate on a medium clay loam. Crops were decidedly poor in the presence of 0.2% Na_2CO_3 in a sandy soil, and showed some signs of distress in the presence of as low as 0.05% of this salt when present in the first or second foot of soil. In the presence of sulphate salts or carbonates, the order of tolerance of crops after the plants were established seemed to be: western rye grass, brome, Kentucky blue grass, meadow fescue and Alsike clover. Peas germinated better than most crops but usually died in soils containing a high salts content when approaching the flowering stage. Flax was quite susceptible to alkali injury. Barley appeared slightly more tolerant than wheat after germination but the germinations of the two were quite similarly affected.

TABLE 4.—GERMINATION AND YIELD OF WHEAT ON SOIL CONTAINING VARYING AMOUNTS OF SALTS

Kind of salts	Per cent salt	Per cent germination	No. of plants	Grain straw, grams
Na_2SO_4	0	97	10	4.23
	.25	93	87	5.83
	.50	80	77	4.42
	.75	73	73	7.93
	1.00	27	3	4.35
	1.25	27	2	2.30
	1.50	27	3	4.15
$MgSO_4$	0	97	10	4.23
	.30	97	87	6.30
	.60	83	77	4.42
	.90	93	87	5.02
	1.20	87	80	5.83
	1.50	90	80	4.18
	1.80	93	87	2.52
Na_2CO_3	0	97	10	4.23
	.025	77	8	4.42
	..10	90	9	5.50
	.20	83	8	4.62
	.40	73	7	4.55
	.60	53	5	5.97
	.80	10	0	0
	1.00	3	0	0
NaCl	0	97	10	4.23
	.025	90	8	3.80
	.10	97	9	3.91
	.20	80	7	3.42
	.40	87	9	4.10
	.60	60	5	1.73
	.80	17	2	.18
	1.00	23	2	.27

Ameliorating Influence of $CaSO_4$

When gypsum was applied in connection with sodium and magnesium sulphate, it showed a very definite ameliorating action on the harmfulness of these white alkali salts. Almost normal growth of both barley and wheat was secured with a mixture of 2.5% of equal parts of sodium and magnesium sulphate where 2% of gypsum was added, while this concentration of these salts completely prevented germination where no gypsum was present. This beneficial action of gypsum was decided in all the replications of the experiments and while it had not been recognized by many soil chemists at the time these experiments were made, the modifying action of one ion in solution upon the harmfulness of another has been frequently observed since that time. A discussion of this interesting phase of the alkali problem will not be entered into here but its importance should not be overlooked by those who are working with soils having a high gypsum content.

TABLE 5.—THE AMELIORATING INFLUENCE OF GYPSUM ON THE TOXICITY OF EQUAL PARTS OF SODIUM AND MAGNESIUM SULPHATES ADDED TO SOILS AS INDICATED BY THE GERMINATION AND YIELD OF WHEAT AND BARLEY

Per cent of Na_2SO_4 and $MgSO_4$	Per cent of $CaSO_4$	Germination		Yield	
		Wheat, %	Barley, %	Wheat, grams	Barley, grams
0.0	0.0	97	90	4.23	16.09
0.5	0.0	93	93	5.05	16.48
0.5	0.5	73	90	3.38	19.30
0.5	1.0	90	83	4.85	16.65
0.5	2.0	70	93	3.23	18.65
1.5	0.0	73	80	2.42	10.50
1.5	0.5	70	57	2.93	7.40
1.5	1.0	70	80	3.08	7.20
1.5	2.0	87	83	2.78	5.53
2.5	0.0	0	0	0.0	0.0
2.5	0.5	0	0	0.0	0.0
2.5	1.0	13	13	5.22	6.07
2.5	2.0	80	83	4.28	13.55

SUMMARY

1. Alkali salts in the heavy soils of the Tilley, Alberta area are composed almost entirely of sodium and magnesium sulphates with considerable quantities of calcium sulphate.

2. The greatest concentrations of salts in virgin soils of low permeability were in the third or fourth foot while in more permeable soils the greatest concentrations were in lower depths. There was a definite leaching downward of the salts with irrigation.

3. Sodium sulphate was much more injurious than magnesium sulphate in these soils. When more than one salt was added to the soil the toxicity of $NaCl$ or Na_2CO_3 did not appear to be added to that of Na_2SO_4, but this was not true of Na_2SO_4 and $MgSO_4$.

4. Calcium sulphate added to soil in large amounts did not decrease germination nor yields of wheat and barley, but where used in connection with Na_2SO_4 and $MgSO_4$ it definitely decreased the harmfulness of these salts.

SOME COMMENTS ON SOIL SURVEYING IN CANADA[1]

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The history of soil surveying in Canada is a comparatively short one. The first attempt at mapping soils in this country was made by the Topographical Survey of the Dominion Department of the Interior in 1919. Two years later soil surveying was started in and by the Provinces of Alberta and Saskatchewan. In the succeeding years most of the provinces entered this field of work until at the present time, seven of the nine provinces are carrying on soil surveys. The Topographical Survey, greatly curtailed their activities in 1925 and finally withdrew entirely from this work in 1930.

With the exception of the mapping done by the Topographical Survey, soil surveys have always been under the direct control of the provinces, the work being conducted either by the colleges or the Departments of Agriculture. The Federal Government, however, did not lose interest in this field with the cessation of activities by the Topographical Survey, as through the Dominion Department of Agriculture, financial aid has been given to the provinces for the encouragement of soil surveys. However this Department has never assumed any direct responsibility for the field work nor the manner in which the data was presented on the maps.

The organization of soil surveys in Canada is, therefore, such that there are at the present time seven distinct bodies in charge of this work, each of which receives financial assistance from the Dominion as well as from the Provincial Governments. Except for such voluntary co-operation as is possible, no provisions have been made for keeping these bodies in contact with each other.

While this setup has the merit of placing the direct responsibility of soil surveying in the hands of the men who are the most familiar with the soils and soil problems of each province, it has resulted in a lack of uniformity in the systems of soil classification in use, in the kind and amount of information relative to soils that is obtained and in the manner in which the data is presented on the soil map. Considering each province as a separate and distinct unit the soil survey methods in use have given good results but when each province is considered as only a part of the whole country, the results are not entirely satisfactory. The differences in the methods of soil classification, even though many of these differences are more apparent than real, and the various ways in which the soil maps are prepared, detract from the value of the work and constitute a limiting factor in use of the soil maps to the fullest advantage. Soil maps are not the easiest kind of maps to understand and the more the maps can be standardized the greater will be their value to the men who are interested in the soils in the different parts of this country.

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[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

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The systems of soil classification that are being used in Canada are those that seemed to best fit local conditions and needs. Each individual in charge of soil surveys necessarily looked upon classification from the standpoint of his own experience and consequently several different systems of soil classification have emerged. The soils surveyors cannot be criticized for not developing a uniform system applicable to all the provinces for to do this it would be necessary to see all the soils in their natural habitat which requires time, travel, and resources, and such facilities were not available to them. Even within each province, the same system of soil classification could not always be adhered to for as the soil surveyor progressed in his work different soil conditions were encountered which sometimes necessitated a change or modification from the original scheme. In fact, soil surveying in this country is still in a state of flux.

With the knowledge that the soils men now have of the nature of the soils in Canada, a uniform system of soil classification that would be applicable to all the provinces could probably be devised without any great difficulty. However, the wisdom of adopting such a system of soil classification for the reconnaissance type of survey is open to question, for it is more important that the surveys within a province be uniform than that there should be uniformity between the provinces. However, in regard to such details as stoniness, textures, and topography, uniformity could be attained without disturbing the classification scheme in use.

There are other types of soil surveys, however, where a uniform system could be used, particularly in those provinces where the soils and the problems in connection with them are similar. Examples of such surveys are the detailed mapping of problem areas and the preparation of maps based on the reconnaissance soil survey which will more clearly interpret to the layman the practical significance of the different types of soil.

Even though it may be impractical to adopt a uniform classification for the reconnaissance surveys, the soil maps based on such surveys could be greatly improved if more uniformity was attained in their preparation. Some of the differences that can be observed in the present soil maps are in regard to the scale of mapping, the amount and kind of information concerning the soils, the use of symbols, and the colours used to denote the different soils. Of these, the last probably gives rise to the most confusion.

The most obvious feature of any soil map is the colour scheme which is used to show the location of the different soils. When any particular soil map is studied each colour becomes associated in the reader's mind with a particular type of soil. But unfortunately, this association, which has taken some time to learn, is not applicable to the maps from other provinces, as each province uses a different colour scheme. It can be readily understood that this lack of standardization adds to the difficulties in reading soil maps. This, particularly, is the case when adjoining soil maps from two provinces are being examined, where similar soils occur on both sides of the border.

Owing to the number of soil types in this country, and even in any one province, it would be impossible to allot a colour for each type of soil. However, soil surveyors should be able to attain at least some degree of a standardization on this matter without any great difficulty. One scheme

would be to use a certain range of closely related colours for heavy soils, another for light soils and another one for the intermediate soils. Soils such as peats and mucks, alkali soils, and soils with a well developed solonetz structure, could be allotted distinct colours. From the agriculturists' viewpoint these are the most important divisions within the broader categories which are usually of such size as to enable their separation to be made with solid or dotted lines.

Many problems must be solved by the soil surveyors in the different provinces before their work reaches the degree of uniformity that would seem to be desirable. I realize that owing to the distances between them that close co-operation is difficult to attain but any joint effort that the soil surveyors can make in standardizing their work would be well worthwhile.

THE APPLICATION OF SOIL CONSERVATION SURVEYS TO SOIL CONSERVATION PRACTICE IN THE UNITED STATES[1]

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United States Soil Conservation Service

Assuming that most of those present are not very familiar with the organization and objectives of the U.S. Soil Conservation Service, I should like first to deal briefly with these matters. This, I believe, will serve as a useful foundation for developing the subject suggested to your program committee, namely, "The Application of Soil Conservation Surveys to Soil Conservation Practice in the United States."

The Soil Conservation Service is a regular bureau of the United States Department of Agriculture and is organized on a civil service basis. As its name indicates, the Service is primarily concerned with the conservation of soil; and, as soil losses are caused largely by accelerated erosion, the Service has always given special attention to the control and prevention of erosion. And, as erosion control is closely related to flood control, grazing control, irrigation practice, moisture conservation and other fields, this aspect of our work has broadened considerably.

In the set up of the organization there are divisions dealing with conservation and watershed surveys, conservation operations, co-operative relations and planning, research, personnel and training, and business management. In the Division of Research are branches engaged in climatic and physiographic investigations, sedimentation and river hydraulic investigations, erosion and farm economics, erosion investigations, watershed and hydrologic studies and hill culture. In the Division of Conservation Operations are branches dealing with agronomy, erosion control practices, engineering, woodland management, nurseries and wildlife management. In the Division of Co-operative Relations and Planning are branches dealing with information, co-operative planning and co-operative relations in extension. Dr. H. H. Bennett has been Chief of the Service since the time of its inception.

Much of both the administrative and technical work has been decentralized by organizing the United States into eleven regions, each with a regional office with units of organization generally corresponding to those in the Washington headquarters. Each region is headed by a Regional Conservator who is responsible for all the demonstration projects and associated Civilian Conservation Corps work camps. A special official is appointed for each state, known as a State Co-ordinator, whose duty is to co-ordinate the work of the Service with the state authorities and with other federal agencies working within the state.

There is a very interesting feature in the organization of our Service which has given it considerable strength and which has served to maintain a high tenor of enthusiasm among its personnel. I refer to the provision

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whereby in Washington, in the Regional headquarters and in the demonstration projects, there are included on the staffs a variety of agricultural technicians whose technical advice is ordinarily needed to solve the problems which most projects have to meet in their efforts to control erosion and to properly readjust land use. Most projects have soil specialists, agricultural engineers, agronomists, specialists in erosion control practices, and specialists in education and information. Where needed, there are also specialists in forestry, range management, wildlife management, and in other fields as needed for special situations. This permits the constant pooling and application of a wide range of technical agricultural knowledge to specific problems on individual farms or ranches and in particular project areas. It is felt that the problems are too complex for one specialist to solve alone.

In the drive toward its objective of conservation of soil and desirable land use readjustment, the Service has, since its organization, worked toward this end on the basis of demonstration projects. The program of these demonstration projects is based on the development of integrated land use in which the farms selected are all located upon one major watershed. The integrated land use that is promoted over the watershed is intended to give as near complete control of erosion and floods as is feasible and practical. It is also intended to develop systems of land use that are adapted to the physical requirements of the region and that are economically sound and adequately stable.

It is hoped that the practices developed and demonstrated on the projects will be adopted by neighboring farmers as well as by farmers operating under similar conditions but located at considerable distances away from the project. Hundreds of projects and associated work camps have been initiated in the United States. Some have been conducted for a long enough period to complete the physical phases of the work and have been placed on a maintenance basis.

The operations on individual farms are conducted under five-year co-operative agreements. These are legal contracts between farmers and the Government, in which each party agrees to certain contributions in the way of technical advice, materials, labour, surveys, farm adjustments, etc. By adjustments I refer to changes which the farmer agrees to make in his farming plans and operations, such as taking certain lands out of cultivation, changing cropping systems, changing fences, reducing the number of livestock on a given piece of pasture land, etc.

The conservation survey is the initial step in preparing for the work programs, and is the foundation for most of the erosion control and farm readjustment operations. It is made before the agreements are drawn up and the work plans formulated.

The conservation surveys are made according to a standard handbook supplied to all field men, entitled *Procedure for Making Soil Conservation Surveys*. Where available, air photographs are highly favoured as base maps, especially for detailed surveys. A scale of eight inches to the mile has been used on the majority of projects on farm land. On range land scales of two to four inches per mile have been more popular.

In the standard conservation survey four factors are mapped, namely, character and degree of erosion, land use or cover, per cent and class of

slope, and soil. These are indicated in a four point fractional symbol as follows:

$$\frac{\text{Erosion} \quad \text{Land Use or Cover}}{\text{Slope} \quad \text{Soil}}$$

Standard symbols are used for each intensity of each factor indicated. Numbers, letters and special symbols are used for this purpose.

A new boundary is drawn when there is a significant change in any single factor, and the full quadruple symbol is shown for each area delineated.

Sheet erosion is indicated by numbers to represent varying degrees, based on the percentages of the various soil horizons removed.

Gully erosion is also indicated by numbers, to indicate frequencies and by special symbols to show relative depth and relative susceptibility to further deepening.

Wind erosion conditions are indicated by letters to express varying degrees of removal and deposition.

Special symbols are also used to indicate stabilization of erosion, either complete or partial.

Land use is indicated by letters under the categories of cultivated, idle or abandoned, forested and pasture land.

Slopes are expressed in groups in relation to the possibilities of controlling erosion according to the more common types of land use. The average per cent of slope is also usually expressed.

Soils are mapped as soil types according to the system established and followed by the U.S. Bureau of Chemistry and Soils.

Although the conservation survey is a big job in itself, it is merely the start of the soil specialist's project duties. His really big job and his most important one is to apply this basic survey data or inventory of physical conditions to operations and project field practice. This involves a careful study and analysis of the data and its simplification and interpretation for the use of the agricultural engineer, agronomist, range specialist and other technicians. Usually, however, the survey data alone are inadequate to supply the operations technicians with the necessary information to work out a practical operations program. Additional information is usually needed. This is obtained by those engaged in research and also by what might be termed as service work or "quick tests" made by the soils men. These may include observations of simple soil moisture dynamics, soil reaction, dispersion and shrinkage behaviour of soil types, and plant-soil correlations.

As the surveys are completed and necessary supplementary information gathered, the combined data are analyzed and a program of erosion control and land use readjustment worked out by the various technicians working in close co-operation. The suggested plan is submitted to the farmer co-operator and when a plan agreeable to all concerned is finally adopted the co-operative agreement is drawn up and signed and the work program is started.

It requires little stretch of the imagination to realize how the survey and information gathered by the soils men may be usefully applied to operations. In fact, it requires a greater stretch of the imagination to figure out how such a program would be possible without these preliminary

data. The map showing the fourfold situation of soil, slope, erosion and land use is a basic picture of the land and its present utilization. A consideration of at least these four factors is necessary.

Two basic objectives of operations are to slow up the rate of flow of run-off water and to make the water sink into the ground at or near where it falls as precipitation. To accomplish this many areas of steep lands and severely eroded lands are retired from cultivation; vegetative cover is improved; various types of contour tillage and contour cropping are practised; water is diverted from critical places such as gullies or valuable lands subject to overwash or flooding; grazing is regulated; and various other methods with the same general objectives are followed. In addition, special measures are used to combat erosion damage by wind; for example, strip cropping, the use of stubble and crop residues, and the promotion of resistant types of soil structure.

In all of this work it is obvious that an accurate knowledge of soils, erosion, and related conditions, such as slope and vegetative cover, is necessary to work out the most practical and suitable program for correcting undesirable conditions prevailing in or threatening a given agricultural area. It should be equally obvious that such a program can be worked out only by the soils men and other technicians pooling their knowledge and viewpoints and working in close harmony toward a common end. The Soil Conservation Service has provided the opportunity for the various agricultural technicians to work in this manner in direct contact with the farmers and under actual field conditions. The Service is conducting a broad co-ordinated program over a wide range of conditions existing in the United States; and it will be highly interesting to study the various methods used and results obtained in this nation-wide battle to control erosion and to reorganize land use on a basis that is relatively permanent and economically sound.

INTER-PLANT VARIATIONS IN CERTAIN SEED-SETTING PROCESSES IN ALFALFA

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[Received for publication August 23, 1937]

INTRODUCTION

Alfalfa (*Medicago sativa* L. and related species with their various strains) has long been regarded as one of the most valued types of plant for forage purposes, but the uncertainty of satisfactory seed production, characteristic of alfalfa, has been a general problem of considerable economic importance. During the past 25 or 30 years many investigations bearing on this problem have been conducted under the diverse conditions of different geographical locations. Most of these investigations have been concerned with the seed-setting behaviour of plants in general under particular ecological conditions. Observations, however, at the University of Alberta at Edmonton, Canada, have indicated the existence of marked variations with respect to seed yields, and also the probability that these variations are relatively constant for the same plants year after year. It thus appeared that some progress with the solution of the problem of the causes of sterility or low seed-setting in alfalfa might be made by studying some of the floral processes involved in seed-setting and contrasting these processes, as observed in highly fertile plants, with those observed in sterile or very weakly fertile plants. The possibility of devising some method of determining seed-setting or fertility indices for individual plants was also to be kept in mind.

The extensive literature reporting investigations on the relation of seed-setting in alfalfa to ecological and certain other biological factors has been ably reviewed by Englebert (8), Armstrong and White (2), Torrsell (13) and others; hence a literature review need not be included here.

MATERIALS AND GENERAL METHODS

Plants of *Medicago sativa* L. were selected in two groups representing extremes of seed-setting capacity. From a population of over 2000 spaced plants consisting of various strains, many of which had been selfed for two or three generations, 20 plants which had been under observation for three or four years were chosen for experimentation. Nine of these plants had been rated as sterile or very weakly fertile, and the remainder were known to set seed abundantly under Edmonton conditions. The former plants are hereinafter designated "sterile" and the latter "fertile". These experimental plants are described in Table 1.

In October, 1934, the selected plants were transplanted from the field each into a glazed earthenware crock with a hole at the base for drainage and containing about one cubic foot of soil. After a dormancy period in a cool root cellar they were removed to a greenhouse at the end of December where optimum moisture conditions and a temperature of approximately 75° F. were maintained.

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TABLE 1.—DESCRIPTION OF THE EXPERIMENTAL PLANTS

Plant designation	Strain pedigree number	Origin of strain	Flower colour	Growth habit	Fertility classification
37-15s*	S_1.32.28	Grimm, Disco	Greenish yellow	Decumbent	"Sterile"
9-11s	S_1.28.3	Grimm, Grafton's	Yellow	Erect	"Sterile"
6-33s	S_3.33.9	Grimm, Lyman's	Light purple	Decumbent	"Sterile"
19-7 s	S_2.32.11	Grimm	White	Erect	"Sterile"
8-33s	S_3.33.10	Hansen's hybrid	White	Erect	"Sterile"
9-38s	S_2.32.5	Hansen's hybrid	White	Decumbent	"Sterile"
1-12s	S_3.33.1	Ontario variegated	Dark purple	Erect	"Sterile"
3-14s	S_3.33.2	Ontario variegated	Dark purple	Erect	"Sterile"
4-5 s	S_3.33.3	Ontario variegated	Dark purple	Erect	"Sterile"
8-28f	I·28·18	Grimm, Disco	Medium purple	Erect	"Fertile"
23-11f	S_1.31.1	Grimm, Disco	Light purple	Erect	"Fertile"
33-4 f	S_2.32.26	Grimm, Disco	Light purple	Erect	"Fertile"
34-5 f	S_2.32.26	Grimm, Disco	Light purple	Erect	"Fertile"
43-5 f	S_2.32.30	Grimm, Grafton's	Greenish yellow	Decumbent	"Fertile"
43-29f	S_2.32.30	Grimm, Grafton's	Light purple	Erect	"Fertile"
40-10f	S_2.32.29	Grimm, Lyman's	Light purple	Erect	"Fertile"
21-23f	I.31.9	Grimm	Light purple	Erect	"Fertile"
21-35f	I.31.9	Grimm	Light purple	Erect	"Fertile"
10-34f	S_2.32.7	Grimm, Kirk's	Light purple	Erect	"Fertile"
47-5 f	S_1.32.32	Cossack	Bluish	Erect	"Fertile"

* s and f signifiy "sterile" and "fertile" plants, respectively.

Artificial electric light was used to supplement the daylight each day until the middle of March.

On May 7, 1935, the plants were transplanted to the field where they were spaced four feet apart both ways. In order to guard against insect pollination during periods of experimentation a screen house was erected so as completely to enclose the stand of plants.

All flowers taken as samples were fully opened, but had not been unfolded more than three days. Whenever setting of pods or of seed was to be determined, or pollen-tube growth studied, the flowers were tripped artificially in order that the processes involved might not be inhibited by failure of the flowers to trip.

The killing and fixing solution used consisted of 6 cc. of formalin added to 10 cc. of 70% alcohol. Notwithstanding some possible disadvantages in subsequent staining of the material, this fixative proved to be very convenient, since numerous samples of flowers could be taken over long intervals of time and left in it until required for study.

EXPERIMENTS

Percentage of Pods Set

On each of the 20 experimental plants approximately 300 flowers were tested. One-third of these were tripped on July 29, 1935, and the remainder on August 9, eleven days later. After all the unopened flower buds and the flowers already tripped had been removed with forceps, the remaining flowers were tripped artificially, and each raceme was suitably tagged with the date and the number of flowers artificially tripped. The pods from both lots of artificially tripped flowers were harvested on September 5 and counted for each raceme. The number of pods was then expressed as a percentage of the number of flowers on the raceme, which had been artificially tripped. A summary of these data appears in Table 2.

TABLE 2.—NUMBER OF PODS SET PER RACEME EXPRESSED AS A PERCENTAGE OF FLOWERS TRIPPED

Plant designation	July 29		August 9		Both dates		G	H
	A* Number of racemes	B Mean percentage of pods per raceme	C Number of racemes	D Mean percentage of pods per raceme	E Number of racemes	F Mean percentage of pods per raceme	Difference between means for dates (D-B)	Difference as percentage of mean for first date
1-12s	16	0.00	27	0.00	43	0.00	0.00	
4-5 s	11	0.00	33	0.00	44	0.00	0.00	
3-14s	9	0.00	15	0.42	24	0.26	+ 0.42	
8-33s	9	0.00	28	0.89	37	0.68	+ 0.89	
19-7 s	6	2.72	12	1.16	18	1.68	− 1.56	
37-15s	14	1.02	23	3.03	37	2.27	+ 2.01	
6-33s	10	9.43	17	6.71	27	7.72	− 2.72	
9-38s	15	3.77	24	13.94	39	10.03	+10.17	
9-11s	15	7.73	28	13.78	43	11 67	+ 6.05	
40-10f	8	30.41	23	19.38	31	22 23	−11.03	−36.3
10-34f	8	30.05	21	22.94	29	24.90	− 7.11	−23.7
34-5 f	11	73.47	19	26.72	30	43.86	−46.75	−63.6
23-11f	6	61.67	16	43.88	22	48.73	−17.79	−28.8
21-35f	8	63.33	17	53.01	25	56.31	−10.32	−16.3
21-23f	11	90.06	18	35.81	29	56.37	−54.25	−60.2
43-5 f	12	52.36	23	67.01	35	61.99	+14 65	+27.9
8-28f	8	86.81	22	58.34	30	65.93	−28.47	−32.8
33-4 f	10	78.61	20	63.90	30	68.80	−14.71	−18.7
43-29f	9	64.22	15	71.59	24	68.83	+ 7.37	+11.5
47-5 f	8	85.68	18	82.32	26	83.35	− 3.36	− 3.9
								M = −22.3

* Columns of the tables are designated A, B, C, etc., for purposes of easy reference.

It is evident that the results of this experiment confirm the original classification of the plants into the "sterile" and "fertile" groups. However, the differentiacion between the two groups is not as wide as might have been expected, since extremes were sought in the original selections. In some instances the variations between plants within a group are larger than variations becween some plants in the different groups. It seems likely that the mean percentages of pods per raceme would have shown gradations from zero to a very high value had a large sample of plants been taken at random in the beginning of the experiment.

Column D of Table 2 discloses a general tendency for pod yields to be decidedly higher for flowers tripped on July 29 than for those tripped on August 9. It seems possible that the weather subsequent to tripping offers a partial explanation of the difference. On July 31, two days after tripping the first set of flowers, a steady rain continued for about 24 hours when 1.61 inches of rail fell. This was followed by 0.32 inches August 4; 1.08, August 13; 0.21, August 17; and frequent light showers thereafter for a few days. Such weather would be expected to provide very favourable soil moisture conditions for pod development. But the latter part of August was dry and hot, and, while favourable for automatic tripping, would not likely promote the development of pods. It has been reported by Alter (1) and Englebert (8) that rain following fertilization helps to increase the yields of seed.

Torssell (13) also found that seed-setting frequency declined markedly in August during the late stages of the flowering period. He thought the the decline was probably due to the poorer climatic conditions (higher humidity and lower temperature) which prevailed at that time. It would appear that Torssell's decline may have been due to climatic conditions unfavourable to tripping and fertilization, while ours was possibly due to conditions too dry to permit the development of pods after fertilization had taken place. It also seems possible, however, that in both cases the stage of seasonal plant development may have had some effect. Internal plant factors may not promote seed-setting as strongly in the late stages as in the early stages of the flowering period.

Although the general tendency was for higher yields following the first pollinations, this result did not obtain for all plants. Most cases of higher pod setting after the first pollination date were among the "fertile" plants. The variability in pod-setting is also greater among this group. This is probably to be explained by the fact that the "sterile" group set so few pods on either date, that differences in yield among these plants would be small even under optimum moisture conditions. It may be that the variability in the fertile group was partially due to the positions of the racemes on the plants. On the second date it was sometimes difficult to secure enough exposed flowers to make up the required two hundred, and occasionally racemes obscured in shaded portions of the plants had to be utilized. Thus differences in the degree of shading and consequent variations in temperature may have affected the set of pods to some extent.

The Number of Seeds per Pod

After the pods obtained in the previous experiment had been counted, they were decolorized in 70% alcohol. With the use of a strong transmitted light, the number of seeds in each pod was easily counted. Since the numbers of pods obtained from plants in the "sterile" group were not large enough to provide an adequate sample, they were not included in this study. A summary of data is presented in Table 3.

The results indicate that wide variations occurred between individual plants with respect to the number of seeds per pod. It is also evident that the number of seeds per pod, like the percentage of pods set, was reduced in most plants following the second series of pollinations. If the data in Table 3 are compared further with those given in Table 2, it will be noted that both gave approximately the same ranking of plants. This is perhaps to be expected. One may assume that factors tending to increase or decrease the percentage of pods set would have a similar effect on the number of seeds per pods, since both pod-setting and seed-setting are necessarily dependent on fertilization.

However, the fact that the two rankings are not quite the same is of some interest. This indicates that the plants varied in the relative degrees of their reaction, in so far as "percentage of pods set" and "seeds set per pod" were concerned, to the conditions associated with the two dates of tripping. It would seem, however, that more extensive data statistically analyzed would be required before any conclusion could be drawn regarding this point.

In general, there are marked average declines in "percentage of pods set" and "seeds set per pod" from the first date to the second. The average decline in the former is −22.3%, while that for the latter is −7.6%.

TABLE 3.—NUMBER OF SEEDS PER POD FOR THE "FERTILE" PLANTS

Plant designation	July 29		August 9		Both dates		G	H
	A Number of pods	B Mean number of seeds per pod	C Number of pods	D Mean number of seeds per pod	E Number of pods	F Mean number of seeds per pod	Difference between means for dates (D-B)	Difference as a percentage of value for first date
40-10f	32	1.56	47	1.62	79	1.60	+0.06	+ 3.8
23-11f	53	1.91	96	1 54	149	1.67	− .37	−19.4
10-34f	34	1.62	48	1.92	82	1.79	+ .30	+18.5
21-35f	73	1.93	112	1.84	185	1.88	− .09	− 4.7
34-5 f	83	2.21	54	1.96	137	2.11	− 25	−11.3
43-5 f	63	2.46	152	2.44	215	2.45	− .02	− .8
33-4 f	94	2.94	138	2.45	232	2.65	− .49	−16.7
43-29f	85	2.88	143	2.77	228	2.81	− .11	− 3.8
21-23f	100	3.32	68	2.60	168	3.03	− .72	−21.7
47-5 f	101	3.49	182	3.09	283	3.23	− .40	−11.5
8-28f	99	3.62	116	3.03	215	3.30	− .59	−16.3
								M = − 7.6

These values are comparable, since they are both on a percentage basis. They indicate that the change from the first date to the second is much more marked for "percentages of pods set" than for "seeds set per pod". It might possibly be inferred from this that "seeds set per pod" is less likely to be reduced by less favourable environmental conditions during and following pollination, than is the "percentage of pods set". Carlson (5) found that 75% only of the pods set survived until harvest time, 25% being lost probably as a result of unfavourable external conditions. The number of seeds per pod in those remaining would not likely be affected in the same way. Thus, if the number of seeds per pod remains relatively stable for different external conditions, it may be a more reliable index of inherent fertility than either the percentage of flowers represented by pods at harvest time or the total seed yield.

Pollen Viability

Pollen viability as determined by the percentage of pollen germinating on an artificial medium was tested as follows. After trying various concentrations of sugar, it was found that 12% cane sugar added to 1.5% agar-agar gave the best results. The medium was poured into a Syracuse dish, allowed to cool, and a sample of pollen from one plant was dusted upon it immediately. The dish was covered and kept at room temperature for two hours. It was then placed in a cooling chamber at about 0° C. until the germinated pollen could be counted. A few drops of a weak solution of methylene blue placed on the medium just before a count was made facilitated the counting. Since the amount of pollen per anther varied in different plants, no fixed number of flowers was used to obtain a sample. Usually from 5 to 10 were sufficient. One hundred counts were made from each dish using a low-power objective and 10X oculars. Only grains showing unmistakable evidence of germination were classified as viable. The number of pollen grains recorded from each sample ranged from 400 to 1400 varying with the different plants under test. The average was 1100 to 1200 per plant. Samples were taken March 26, 1935, while

the plants were in the greenhouse, and, to represent field conditions, a further set of samples was taken July 8, 1935, from the plants which had been transplanted into the field in the spring. Unfortunately a method of measuring the relative amounts of pollen produced by the different plants was not devised and comparative estimates only of these values are presented. A summary of the results is given in Table 4.

The variability among plants in pollen viability is striking. Values for plants in the "fertile" group are in general higher than those for plants in the "sterile" group. Plant 43-29f appears to be irregular in that it was originally classified as "fertile", but its percentage of viable pollen places it among the "sterile" group for this feature. It varied widely in viability between the two dates, and further checking would seem to be desirable.

TABLE 4.—PERCENTAGE OF POLLEN GERMINATION

Plant designation	Mean percentage germination				Comparative estimates of pollen amount
	A March 26 (greenhouse conditions)	B July 8 (field conditions)	C The two dates combined	D Difference between two dates	
3-14s	17.4	9.2	13.3	8.2	Very low
1-12s	28.8	27.0	27.9	1.8	Low
4-5 s	46 5	19.9	33.2	26.6	Low
9-38s	53.2	28 0	40 6	25.2	Low
6-33s	46 6	43.7	45 2	2.9	High
9-11s	56 0	43.1	49 6	12.9	Fairly high
43-29f	68.3	32.7	50.5	35.7	High
19-7 s	58.9	43 5	51.2	15.4	Fairly high
37-15s	69.3	58.7	64.0	10.7	Low
34-5 f	73.0	69.4	71.2	3.5	High
33-4 f	78.0	66 7	72 4	11.3	High
47-5 f	78.9	71.3	75.1	7.6	High
21-35f	77.8	74 8	76 3	3.1	High
10-34f	84.8	70.7	77.7	14.1	High
8-28f	85.3	76.0	80.6	9.3	High
21-23f	89.3	79.3	84.3	10.0	High
40-10f	89.6	79.2	84.4	10.4	High
23-11f	85.6	79.5	84.6	10.1	High
43-5 f	91.6	84.3	87.9	7.3	High

At first sight it might appear that some relation between percentage of viable pollen and percentage of pods set is indicated, but this is found not to be the case when correlations are calculated for mean "percentage of pods set per raceme" (Table 2, Column F) and "mean percentage of pollen germination" (Table 4, Column C). This applies equally for the "sterile" group, for the "fertile" group and for both "sterile" and "fertile" plants included in a single group. The coefficients of correlation for these groups are as follows:

Group	r	t	P
"Sterile"	+0.336	0.874	0.3+
"Fertile" plants	− .287	.899	.3+
"Sterile" and "fertile" plants	− .119	.494	.6+

These correlation coefficients are small, and in all cases must be regarded as insignificant in consideration of their high P values. The first three plants listed in Table 4, *viz.* 3-14s, 1-12s and 4-5s were low in pollen germination (under 35%), and at the same time set practically no pods, but otherwise the plants in the two groups behaved so irregularly that one is unable to establish any relation between percentage of viable pollen and percentage of pods set.

The plants producing pollen of low percentage viability also produced relatively small quantities of pollen. Perhaps the same causative factors were responsible for both these deficiencies.

It may be that percentages of pollen viability in excess of 40 or 50%, if the amount is fairly high, do not tend to increase the setting of pods. This suggestion is in harmony with conclusions of other investigators; Armstrong and White (2) state that pollen was usually abundant enough for fertilization in both high and low seed-setting plants of alfalfa, and Englebert (8) concluded that 22.5% of sterile pollen was unimportant if the total amount was large. Brink and Cooper (3) found that pollen abortion is not an important factor generally in alfalfa seed-setting.

The general decrease in pollen germination under field conditions as compared with greenhouse conditions (Table 4, Columns B and A respectively) is apparent. The decrease varied greatly for different plants. It is believed that these facts can be explained by regarding the non-germinating pollen as consisting of two types, one composed of the small clear grains which were studied by Clarke and Fryer (6) and found to remain constant for a given plant under wide environmental variations, and the other type composed of normal appearing grains which might have germinated had a more suitable medium been used, or which, on account of their high sensitivity, may have been adversely affected by unfavourable environmental conditions during development.

Pollen-tube Growth Within the Pistil

For this study material was collected from plants growing in the field at two different periods, one commencing on July 31 and the other on August 6. The procedure was to trip on each of these dates a sufficient number of flowers on each plant for the experiment. Lots of about 10 flowers were collected from each plant at successive intervals after tripping. The intervals for the first period were 2.5, 5, 8, 13, 19, 25, 31, 37, 43 and 49 hours; and for the second period, 3, 5, 7, 9, 12, 16, 20, 24, 27, 30, 33, 36, 40 and 48 hours. The varying conditions of atmospheric temperature and relative humidity were recorded for each period by means of a thermohygrograph.

Due to the hard tissue composing the outer part of the style, it was not possible to stain and crush fresh stylar material for microscopic examination. Accordingly, after collection, the material was immediately fixed in the formalin-alcohol solution mentioned previously. Later it was embeded in paraffin, sectioned, stained and mounted in Canada balsam.

Various stains were tried with dissatisfaction, possibly due to the killing solution, formalin-alcohol, which is not usually regarded as a good fixative to precede the use of the best stains. Acid fuchsin, however, was found to give good differentiation in the stigma and ovary, although it was seldom possible to trace pollen tubes within the central and lower

parts of the style. The following schedule for staining and mounting was devised:

1% aqueous acid fuchsin	1 to 2 hours
Distilled water	6 changes
70% alcohol	1 minute
95% alcohol	1 minute
Absolute alcohol	5 minutes
Clear in xylol and mount in Canada balsam.	

It was necessary to use distilled water (pH 4.7) since tap water (pH 7.7) removed the stain in the water changes.

Because of the labor involved in the use of the paraffin method only three plants were studied. These differed widely in their seed-setting capacities. Plant 8-28f was one of the most fertile plants under study; 6-33s set a very low percentage of pods, and 1-12s set no pods.

The records of temperature and relative humidity are given in Figure 1, and a summary of the remaining data is given in tables 5 and 6. It should be mentioned that all numbers of pollen tubes given in the tables are minimum values, since it was often difficult or impossible to be sure of the total number present.

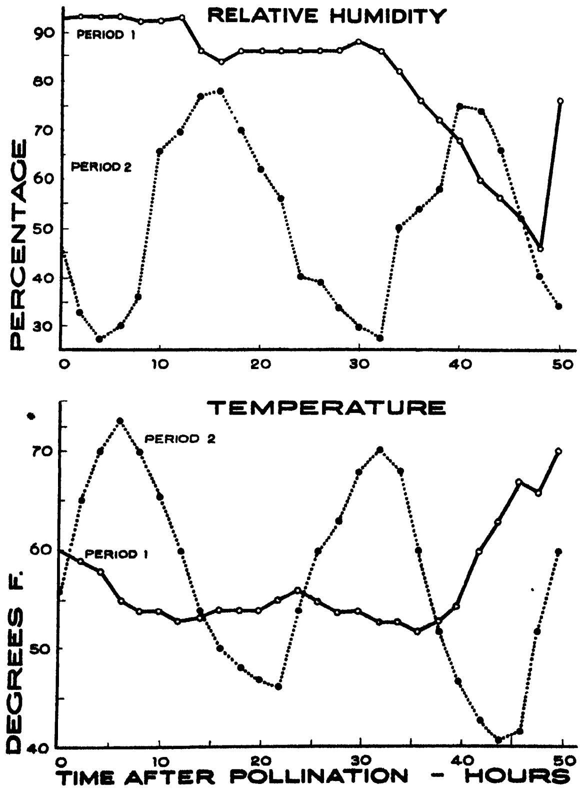

FIGURE 1. Temperature and relative humidity records for two periods during which samples were taken for the analysis of pollen-tube penetration into the stigma and ovary. Period 1 commenced at 4.30 p.m. July 31 and ended 5.30 p.m. August 2. Period 2 commenced at 8.30 a.m. August 6 and ended at 8.30 a.m. August 8.

For the data given in Table 5 only stigmas collected at the first four intervals for each period were used. The values for plant 8-28f are considerably higher than those for plant 6-33s, both in number of stigmas penetrated and in mean number of pollen tubes penetrating. These differences no doubt are largely responsible for the marked difference in fertility between these two plants (see Table 2). Values for plant 1-12s are very low and it would seem that the almost complete failure of the pollen to penetrate the stigmas is responsible for the entire failure of this plant to set pods. However, since there is some penetration, one might expect an occasional pod, at least, to be set (see Table 2).

TABLE 5.—SUMMARY OF DATA RELATING TO THE PENETRATION OF POLLEN TUBES INTO THE STIGMA

Plant designation	Total number of stigmas examined		Total number of stigmas penetrated		Total number of pollen tubes penetrating		Mean number of pollen tubes penetrating	
	July 31	August 6	July 31	August 6	July 31	August 6	July 31	August 6
8-28f	36	36	34	35	270	275	7.5	7.6
6-33s	36	36	28	32	90	178	2 5	4.9
1-12s	35	34	14	3	38	3	1.1	0.1

NOTE:—Mean values include stigmas which showed no evidence of penetration.

To secure the data presented in Table 4 the ovaries collected at each interval were examined and the numbers of pollen tubes present were noted. The differences in this case are relatively similar to, and serve to verify the data given for the penetration of pollen tubes into the stigma, (Table 5). Additional data were obtained on the rate of growth of pollen tubes as indicated by the time from tripping to ovary penetration. The variation in the time interval among the three plants is very marked for the July 31 date, and if the number of pollen tubes present at the interval when penetration was first noted is considered, there are also apparent differences for the August 6 data, particularly between plant 8-28f and the other two plants. These latter variations are probably not very significant, and it may be that under the more favourable atmospheric conditions prevailing at the August 6 date, the differences between plants in the rate of pollen-tube growth tended to lessen.

At this point it may perhaps be suggested that penetration of the ovary by the pollen tube may not necessarily result in immediate fertilization. Although the time at which fertilization occurred was not determined, it was observed that the ovary may be penetrated in the brief period of seven hours. Cooper (7) and Reeves (11) both found evidence of fertilization in alfalfa from 24 to 32 hours after pollination. Thus it appears that a delay may occur between penetration of the ovary by the pollen tube and fertilization of the ovule.

The most striking observation from the data in Tables 5 and 6 is the variation among the different plants. However, there are also differences within the same plant for the two date periods, particularly with respect to the time intervening between tripping and the first penetration of pollen

TABLE 6.—SUMMARY OF DATA RELATING TO THE PENETRATION OF POLLEN TUBES INTO THE OVARY

Plant designation	Total number of ovaries examined		Total number of ovaries penetrated		Total number of pollen tubes penetrating		Mean number of pollen tubes penetrating		Time of first penetration of pollen tubes into ovary		Number of pollen tubes present at time of first penetration into ovary	
	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6
8-28f	74	113	67	112	314	445	4.2	3.9	8 hr.	7 hr.	1	30
6-33s	75	116	47	99	63	174	0.8	1.5	13 hr.	7 hr.	2	2
1-12s	73	112	25	9	35	10	0.5	0.1	25 hr.	9 hr.	5	1

NOTE:—Mean values include ovaries which showed no evidence of penetration.

tubes into the ovary. The difference in this respect between dates for plant 8-28f is only one hour which probably is not significant. The number of pollen tubes present for this plant at the time of the first penetration into the ovary was, however, greatly in excess for the second date over that for the first date. This would indicate a more rapid general pollen-tube growth on this plant for the second period than for the first. Apart from this, plant 8-28f appears to be relatively stable with respect to pollen-tube growth and stigma and ovary penetration under the very different climatic conditions on the two dates of tripping.

For plants 6-33s and 1-12s the differences in time of first penetration of pollen tubes into the ovary between the two dates are six and sixteen hours respectively (Table 6), the less time being required in the second date period for both these plants. These differences are undoubtedly due to differences in the rate of pollen germination and pollen-tube growth, which are probably referable to the different weather conditions immediately following tripping on the two dates. Tripping on the first date was done at 4.30 p.m., July 31, and was followed by two days of wet and cool weather, whereas tripping on the seeond date was done at 8.00 a.m. on August 6, and was followed by low atmospheric humidity and high temperature. Figure 1 indicates the humidity and temperature conditions immediately following tripping on both dates. During the first ten or twelve hours after tripping, when pollen germination and pollen-tube growth would normally take place, weather conditions as indicated by the graphs (Fig. 1) were just the opposite for the two dates.

It would seem, therefore, that, for the relatively non-fertile plants 6-33s and 1-12s at least, the more rapid pollen-tube growth for the second period was attributable either to the lower atmospheric humidity or to the higher temperature or to both. At the same time it seems likely that for these two plants the retarded rate of pollen-tube growth for the first period was attributable either to the higher atmospheric humidity or to the lower temperature or to both. Buchholtz and Blakeslee (4) found a steady increase in the rate of pollen-tube growth in *Datura stramonium* from 52° F. to a maximum at 92° F. Smith and Cochran (12) found 70° F. to 85° F. to be the optimum range of temperature for pollen-tube growth in the tomato. In view of these results it seems probable that temperatures

slightly over 70° F. may tend to accelerate pollen-tube growth in alfalfa, particularly in plants of low fertility as compared with temperatures of approximately 55° F.

It will be noted in Table 5 that plants 6-33s and 1-12s react oppositely for the two date periods, in that the average number of pollen tubes penetrating the stigmas of plant 1-12s was somewhat higher for the July 31 period, than for the August 6 period, while for plant 6-33s the reverse was the case. Perhaps the particular combinations of humidity and temperature conditions to which these plants were subjected during the two date periods may have been responsible for their opposite reactions. Martin (10) and Armstrong and White (2) have shown high atmospheric humidity to be favourable for pollen germination in alfalfa, and Smith and Cochran (12) have demonstrated that 85° F. was optimum for pollen germination in the tomato. Plant 6-33s was a decumbent plant, and it is probable that, at the time of the second pollination, a high humidity was maintained about the flowers on the decumbent branches, and this combined with the higher temperature prevailing at the second date of tripping was likely very favourable for pollen germination. On the other hand plant 1-12s was very erect in growth habit and, consequently, its flowers would be exposed to the more severe drying action of the sun and wind than would be the case with plant 6-33s. Thus, on plant 1-12s, the lower atmospheric humidity in the uppermost flowers at least, may have counteracted the favourable action of the high temperature.

DISCUSSION

This investigation was prompted by two interests in particular, *viz.*, a desire for a better understanding of the floral processes responsible for sterility in alfalfa, and the acquisition of information which might facilitate the development of high seed-setting strains in connection with alfalfa plant breeding projects.

Perhaps the most striking general result is the wide variability in fertility among alfalfa plants enacting seed-setting processes under approximately the same environmental conditions. This variability is evident in all the experiments of this investigation. It has been demonstrated that under varying conditions one plant may react differently, while another may tend to remain relatively stable. These results indicate the action of genetic factors favouring high seed-setting, which have been accumulated in particular plants. Consequently it is suggested by the authors that marked variations in seed production from year to year in a stand of alfalfa may be due, in some degree at least, to a large proportion of unstable individuals which require favourable external conditions in order to set seed freely. A further conclusion is that the few high-yielding plants usually present in poor years represent in such stands individuals so constituted genetically that they are less sensitive to a somewhat unfavourable environment, and are therefore capable of relatively high seed production even though environmental conditions deviate considerably from those optimum for seed-setting.

These studies indicate that the amount and viability of pollen and pollen-tube growth are important factors in contributing to wide differences in seed-setting capacity of plants and also to small gradations in fertility

between plants of the sterile group. When the amount of viable pollen is above a certain level, variations in this may possibly be disregarded as a cause of sterility, provided of course, it remains reasonably constant under varying environmental conditions. However, it appears that within certain limits no single variable feature of the pollen can wholly account for the extreme differences between "sterile" and "fertile" plants. It is also evident that in highly fertile plants these effects are relatively unimportant in differentiating small degrees of seed-setting ability.

A consideration of the temperature and humidity records in relation to the results indicates that in certain plants these weather factors may influence both pollen germination and the rate of pollen-tube penetration. This suggests that environmental factors may be very useful in the detection of unstable plants with constitutions unsuitable for the development by breeding of high seed-setting strains of alfalfa.

Some of the most fertile plants used in this investigation are the products of first and second generations of selfing, and although other workers have found a general decrease in seed yield from selfing, they have also reported plants which have maintained yield and vigour. Thus the results of selfing given by Kirk (9) show maintenance or increase of later generations over parental stock in both forage and seed yields. Similarly Tysdal and Clarke (14) report a selfing project in which seed yields of lines in the fourth generation exceeded those of the parent plants. It would seem, therefore, that selfing may unhesitatingly be included in a program of improvement of seed-setting capacity in alfalfa. Selfing would facilitate the analysis of stocks and progenies for morphological characters and for reproductive stability under the action of somewhat unfavourable environmental factors. It seems probable that combinations of desirable characters including stability of high seed-setting capacity might thus be attained. If growth vigour is reduced in the process, this loss could presumably be recovered by intercrossing of the selfed strains.

SUMMARY

1. Tripping of alfalfa flowers was found not to be the only limiting factor in fertility, since fertility differences between plants occurred after artificial tripping.

2. Marked differences in the number of seeds per pod were found between plants in the "fertile" group.

3. Evidence is presented to show that for "fertile" plants the number of seeds per pod may be a more reliable index of inherent seed-setting capacity than the percentage of flowers which give rise to fully developed pods.

4. When the two dates of tripping were compared, "percentage of pods set" and "mean number of seeds per pod" were lower for the second date. It is suggested that soil moisture and the stage of seasonal development of the plant may have contributed somewhat to these differences.

5. The test of pollen viability on an artificial medium gave wide variations between different plants and considerably higher germination was secured from greenhouse plants than from the same plants grown later in the field. The mean pollen viability (greenhouse and field results combined) ranged from 13.3 to 64.0% for "sterile" plants, and from 50.5 to 87.9% for "fertile" plants.

6. Two classes of sterile pollen were noted. One consisted of clear, empty-appearing grains and the other of apparently normal grains which did not germinate. It is suggested that the latter class may have been in reality viable, but that the particular conditions supplied did not induce the grains to germinate; or that the latter type of grains, being highly sensitive to environmental conditions were adversely affected thereby during the course of their development.

7. Relatively high temperature conditions apparently accelerated pollen-tube growth, though certain individual plants reacted somewhat differently in rates of pollen-tube growth under two different temperature conditions.

8. Penetration of the ovary by pollen tubes occurred within seven hours after tripping on August 6 in the case of two plants, while nine hours were required for a highly sterile plant.

9. It is suggested that an accumulation of genetic factors which contribute to fertility may tend to maintain the seed-setting stability of fertile plants even when the environmental conditions may be somewhat unfavourable.

10. It would seem that self-fertilization may be included in a program of improvement of seed-setting capacity in alfalfa.

ACKNOWLEDGMENT

This investigation was made possible by an allowance from a Carnegie Corporation Grant made to the University of Alberta. The authors wish to express their appreciation for this assistance.

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SCIENTIFIC AGRICULTURE

Vol. XVIII DECEMBER, 1937

THE SOILS OF SOUTH-CENTRAL ONTARIO

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[Received for publication October 15, 1937]

In a previous paper entitled "The Physiography of South-Central Ontario" (5) there was presented an account of the topographic form and nature of the geological material upon which the soils have been developed in that part of the province lying between Lake Ontario and the Pre-cambrian Shield and bounded on the west by the Niagara Escarpment from Hamilton to Collingwood. Such information is a necessary background for a description and classification of the soils in this region because of its complicated geological history and the comparatively youthful development of the soils themselves. For the most part the area has a deep covering of drift, the soft limestones and shales which constitute the underlying bedrock being a prolific source of material. The rough, hilly, sandy moraine running east and west through the centre, the rolling ground moraine with its attendant drumlins, the gravelly beaches, the sands and fine sands of the deltas and the level beds of silt and clay in the old lake bottoms provide the parent materials for an extremely variable and interesting group of soils. Thus, having clearly in mind the physiographic nature of the country, it is proposed in the present paper to proceed to a description of the outstanding soil characteristics, and to classify the chief land types.

PEDOLOGICAL FACTORS

It is an accepted fact that the character of the soil is influenced more by climate than by any other factor. Climate and the associated vegetation govern the type of leaching process which operates in any given region, and these factors largely govern the distribution of the major soil groups of the world. Locally, however, the important soil differences are the results of the depth, form and nature of the drift and the attendant drainage conditions.

That part of Ontario discussed herein lies in the podsolic zone, but the soils are largely grey-brown podsolic soils rather than mature podsols. In the more northerly and easterly sections, true podsols occur in sandy areas where drainage is imperfect but they are not extensive.

The geological material is especially important, in view of the highly calcareous nature of much of the drift, since it gives rise to "endodynamorphic" soils; that is, soils which are abnormally characterized by the parent material because of the degree to which it has resisted the processes of weathering. This is manifest in the large tracts of alkaline soil in which

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it is not uncommon for virgin soil in well-drained locations to have carbonates in the surface horizon, while, in the cultivated fields of over one-third of the area, free carbonates are present in the plowed layer. Some of the calcareous soils are poorly drained but most of them are well drained and have a good horizonal development with zones of eleuration and illeuration typical of the podsolic soils. It is perhaps worthy of note, that free carbonates are present in the A_1, but absent in the A_2 and B horizons.

While soils formed on such calcareous materials are in some respects related to the "Rendzina" group (2), their descriptions do not correspond in that they lack the deep, dark surface layer, and have the normal horizonal development. They are unusually alkaline soils to be found in a humid region such as this, and are looked upon by the authors as intrazonal members of the grey-brown podsolic soil group.

In the south-western part of the area, where the till contains a high proportion of shale; on the northern uplands of Simcoe county, where there is a predominance of Archaean material in the till; and in well drained sandy areas, generally, there are to be found acids oils with typical regional characteristics.

CLASSIFICATION

In the area under discussion there are between 35 and 40 distinct types which would be isolated, described and mapped in the course of a detailed soil survey. Some of them are well known types, previously described, since they occur in other parts of the province where detailed soil surveys have been made by the Department of Chemistry of the Ontario Agricultural College; but the majority are new or different. In this paper it is not proposed to describe the individual soil types, but rather to group similar types and to describe them under broader units as "land types," which, in the process of description, will be named according to their outstanding characteristics. From a taxonomic point of view, these soil divisions are somewhat similar to the land types and sub-types described by Veatch (7) in the State of Michigan. It is an arbitrary grouping of soil types which have similar profile characteristics, uses, values and crop adaptations.

Having, from observation in the field and from the results of chemical tests, obtained a survey of the chief characteristics of the soils throughout the area, the information for each factor has been placed on a separate chart in the following series. In this way, it is hoped that a graphical presentation of those factors which limit the use of land and affect its cultural treatment will be effectively achieved. Subsequent to the discussion of the physical and chemical characteristics, the land types will be described and their geographic distribution indicated.

For some purposes the ultimate soil type is none too fine a definition of soil character; but in certain ecological studies, such as variety testing, it is necessary for practical purposes to deal with groups of similar types. Furthermore, such treatment has the advantage of preventing a report of this sort from becoming unduly cumbersome.

Physical Characteristics

Of the factors which limit the use of land, the physical characteristics such as topography, depth to bedrock, texture and drainage are more influential than the chemical factors. Soil reaction and fertility levels are

certainly important, but the farmer can alter them to some extent as required. He must, however, plan his type of agriculture to fit the existing conditions of topography, texture, and other factors.

Topography

Because it limits the use of land, the proportion of an area which is too steep to permit of cultivation is of special interest; moreover, the degree of slope is important in relation to soil erosion. Figure 1 is a relief map of south-central Ontario indicating the chief topographic forms. An outstanding feature is the interlobate moraine, running through the centre of the area, on which there is a large proportion of land too steep for cultivation. There is considerable erosion on the steep hillsides, and as much of the soil is sandy, it tends to promote soil drifting.

In the drumlin belt, the topography, while quite rolling, generally permits cultivation although many of the larger and steeper hills have retained a strip of rough pasture or forest along their sides because of the slope. Such drumlins are most abundant in the counties of Peterboro and Northumberland. The more irregular hills of the limestone moraines also have much land which is too steep for cultivation.

On the south slope, facing Lake Ontario, and particularly in Durham county, the till plain is dissected at frequent intervals by abrupt gullies which interfere with cultivation. Incidentally, these gullies probably constitute the most definite erosion problem to be seen in any part of the area. The uplands of Simcoe county include some very steep hillsides, the old shore cliffs of Lakes Algonquin and Iroquois are usually too steep for cultivation, and finally, the Niagara Escarpment gives rise to a strip of rough, hilly land from Hamilton to Collingwood. It is probable that about 7 or 8% of the total area is too rough and steep for cultivation. The remainder, consisting of level lake plains, undulating ground moraine and rolling drumlins, constitutes ideal arable land.

Depth

The depth of the drift over the bedrock in various parts of the area is indicated in Figure 2. The limits imposed by extremely shallow soil such as that of the Napanee plain or the northern part of Victoria county are obvious. However, in the second division outlined on the map, where, although the bedrock only occasionally appears on the surface, it is, as a rule, covered with a rather shallow mantle of drift, the effect is, perhaps, not so well understood. It is here that shallow rock basins and blocked drainage channels cause so much of the area to be poorly drained or swampy; while a combination of factors, including stoniness and the presence of bedrock barriers make it difficult to instal tile drains.

Much the larger area consists of deeper drift in which drainage is not so restricted. Proper surface channels have been formed in most cases, and in the few cases where needed, artificial drains are comparatively easily installed. In the deeper drift there is also better internal drainage which allows the processes of weathering to take place more rapidly, resulting in a more advanced development of the soil.

Drainage

In Figure 3 is shown a survey of the general drainage conditions of the soils in the region. To a considerable degree, the drainage is governed

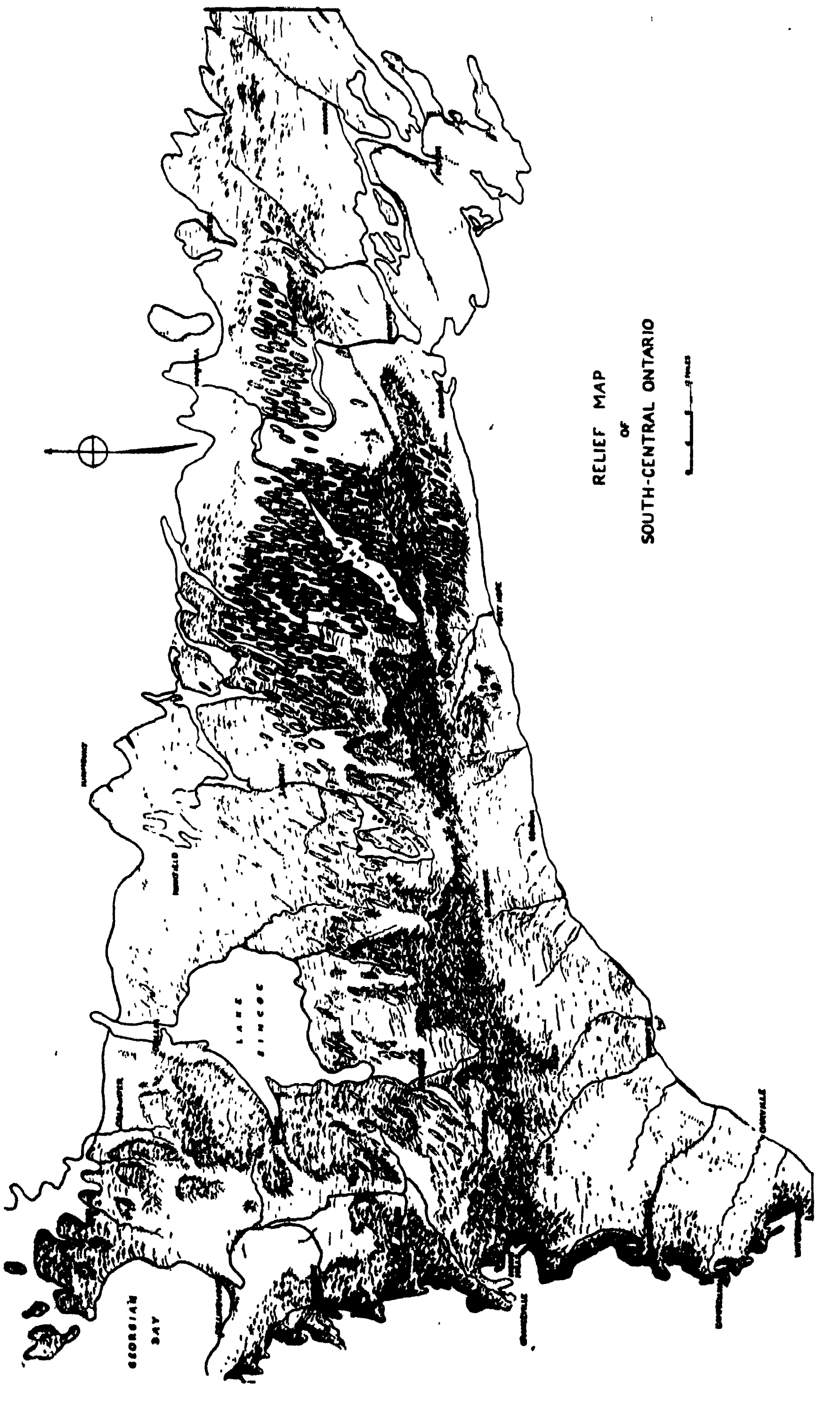

FIGURE 1. The chief topographic features of the area.

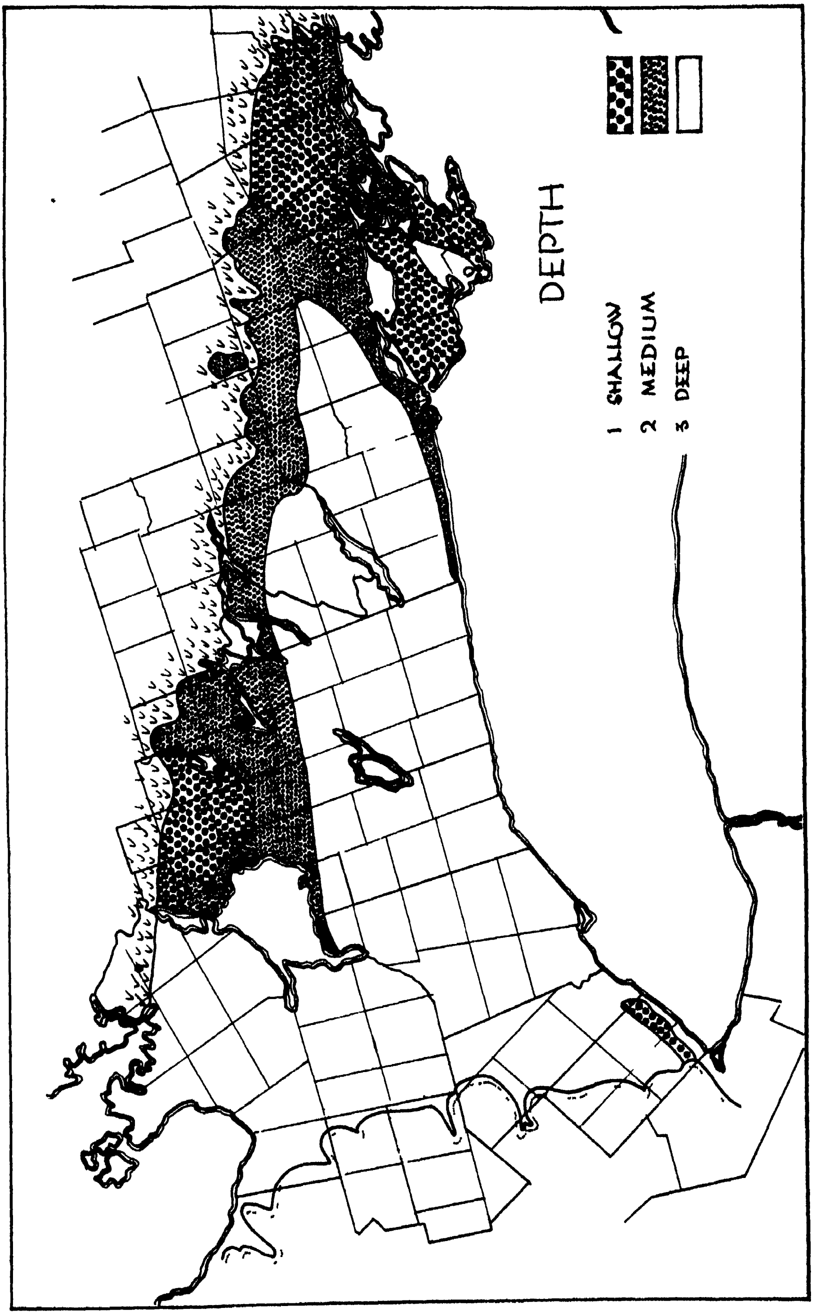

FIGURE 2. A general chart of the depth to bedrock.

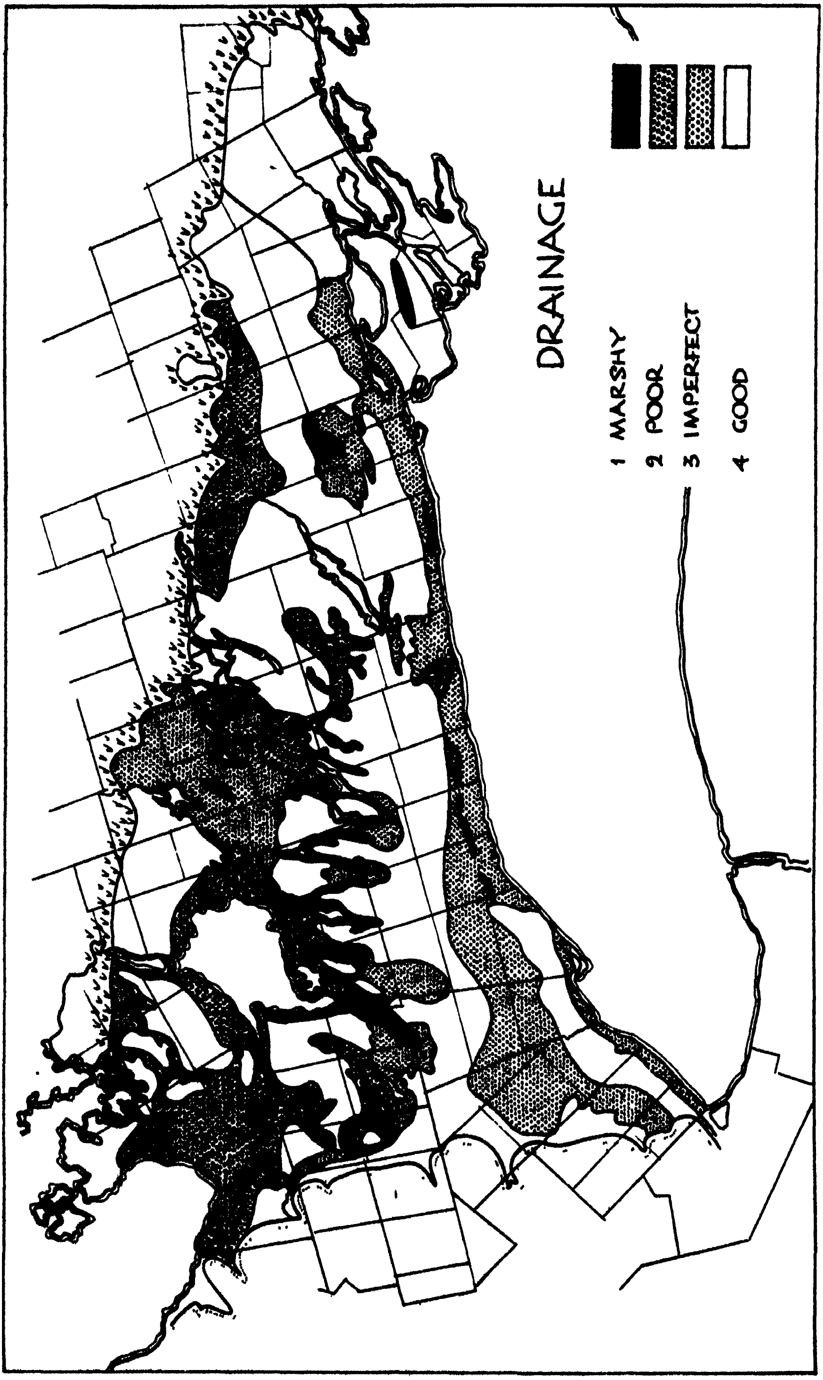

FIGURE 3. A general chart of drainage conditions.

by the topography, and it is generally considered that the greater the relief of an area, the better the drainage, but there are notable exceptions. In some level areas, as for instance, in the vicinities of Camp Borden and Alliston, there are deep sandy soils which have good vertical drainage. In the Peel plain there are heavy soils which are as well drained, although more nearly level than the rolling till soils adjacent. Both have similar clay subsoils, but the former have uniformly fine textured surface layers, while the latter class has a somewhat lighter, more gritty surface which becomes more readily waterlogged. In the southern part of Oro township there are rolling areas in which the soil has poor internal drainage, while a similar condition occurs in Darlington township where there is a light loam or sandy loam surface over a heavier subsoil. It is worth noting that as a rule those soils which are most uniform in texture throughout their profile possess the most desirable drainage conditions; whereas excessive textural differences are likely to interrupt the natural movement of water in the soil.

One of the commonest causes of poor or imperfect drainage is the presence of seepage from areas at higher elevations. Springy spots are common along the sides of many drumlins, a condition which it is almost impossible to correct effectively by means of tile drains.

Poorly drained areas are frequently encountered in association with the shorelines of the extinct lakes. There are many seepage areas at the foot of ancient shore cliffs. Where well-formed beach lines exist, there is usually a depression on the shorewood side, which receives and holds the run-off water from the higher land. "Boulder pavements", besides being very stony, are often also very wet. In the other hand, the beaches themselves, because of the coarse sand and gravel which they contain, are too well drained and often drouthy. For these reasons, a strip of waste land sometimes a mile or so in width, is found fairly consistently, just inside the Iroquois shoreline from Toronto to Trenton. Similar areas are found at many points along the shore of Lake Algonquin.

Those areas in which there is only a shallow mantle of drift overlying the bedrock are a mixture consisting of well-drained knolls and ridges either surrounded by or enclosing swamps of varying degree. Long narrow swamps are often found in the valleys of northward flowing streams. Drumlinized country also contains some narrow swampy basins lying between the hills. There are also marshy areas bordering many of the existing lakes.

Finally there is to be considered those extremely shallow soils which present conditions thwarting description on an ordinary chart. In many places the bedrock has enough relief to permit continuous free drainage, but over much of the more nearly level areas the soil may virtually be said to be at all times either too wet or too dry. With downward percolation prohibited, the few inches of soil readily become saturated during a rain, but with equal rapidity it again becomes dried out and parched.

Texture

The prevailing texture of the surface soil is shown in Figure 4. A map of such small scale of necessity includes very little detail and it is therefore expedient to point out some of the features which cannot be graphically expressed. The areas of coarse sands actually include inliers

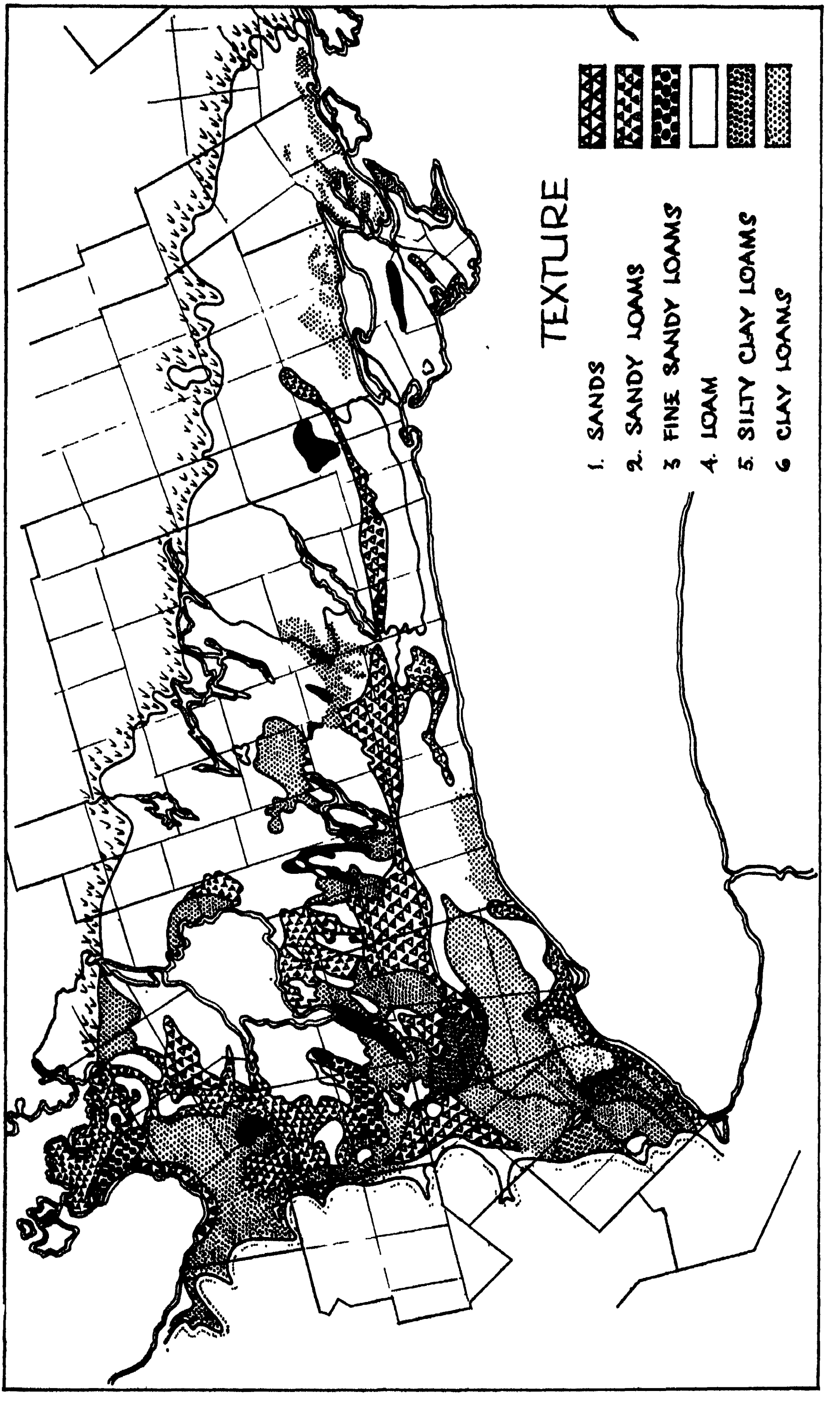

FIGURE 4. A general chart of the texture of the surface soil.

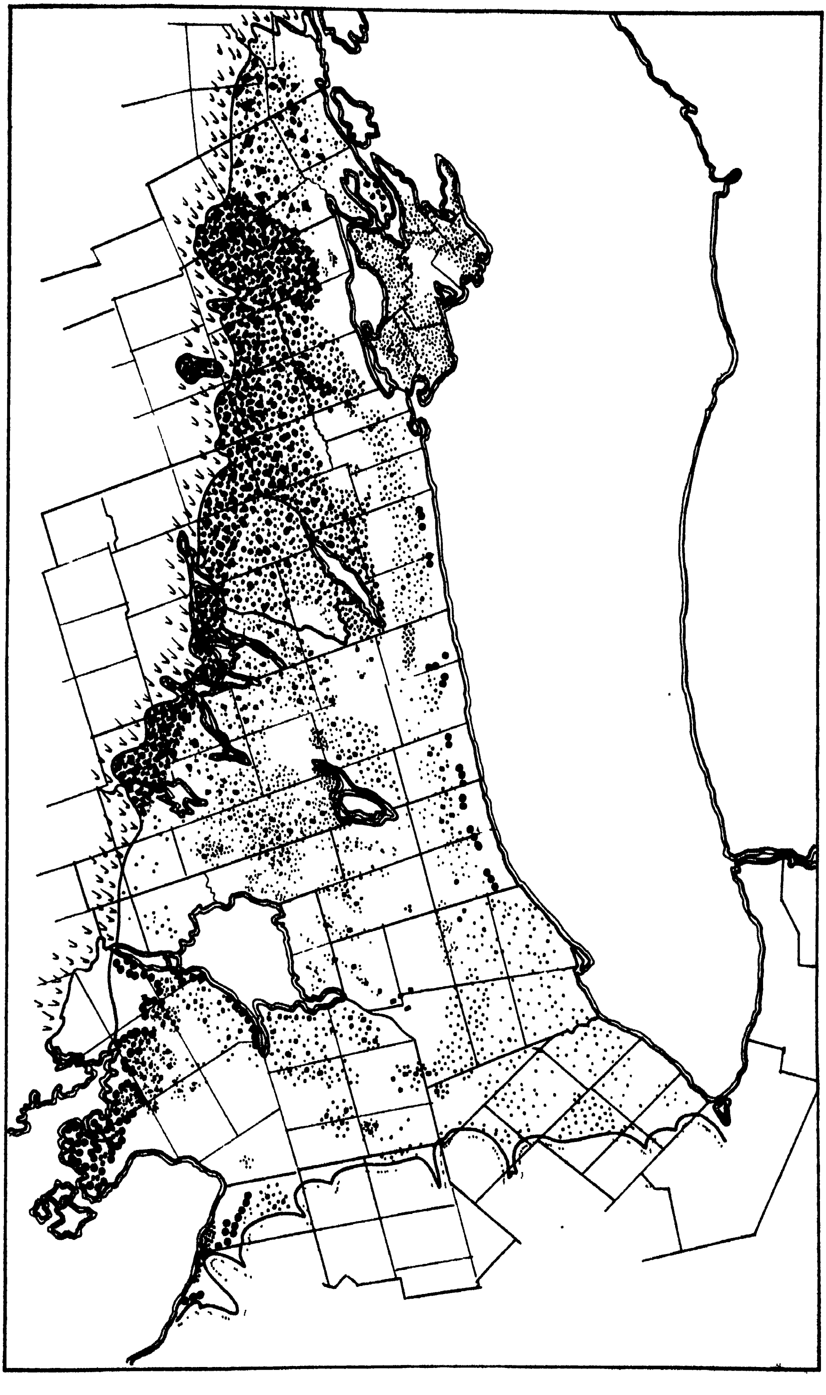

FIGURE 5. A chart of the relative stoniness of the soil

of sandy loams and fine sandy loams as well as occasional knobs of clay. In north Simcoe the soil on the uplands is classed as a loam, although in actuality it becomes more sandy as one proceeds northward, so that much of it is a very light loam. Similarly in Victoria county, the soil varies from a stony clay loam in parts of Mariposa township to a sandy loam farther north in the vicinity of Cameron Lake. The soil in the Peel Plain is a heavier clay loam than is the till soil common to Chinguaconsy township. In the Iroquois plain between Toronto and Hamilton there are areas of clay loam, especially some heavy red clay near Burlington, but the predominant soils are sandy loams developed on the old Iroquois deltas of the streams which now flow through them into Lake Ontario. The sandy and gravelly soils of the old beach deposits of Lakes Iroquois and Algonquin are not represented on the chart; neither are the esker ridges which are so abundant in the broad area of loams in the drumlin belt. Both these features are the causes of important soil differences but since they exist as very narrow strips, they cannot be shown on a small-scale map.

Structure

By "structure" is understood the degree of compactness or of crumbiness, the physical condition of, rather than the size of the soil particles. In this regard the heavy soils are our main concern since the sandy loams are single-grained in structure, and the loams are usually friable and easily tilled. Clay loams, however, may vary widely in their structure. For instance, the clay loam in the Peel Plain to the east of the Credit River has an exceptionally good crumb structure, and in the spring it is particularly noticeable that this soil will be loose and crumby, whereas the adjacent acid clay loams on the shaley till will be much more compact and consequently more difficult to work into shape as a seed bed. A similar good structure is possessed by the calcareous clay loams of the Schomberg lake plain, while the heavy acid soils on the marine clays of the Napanee plain may have a physical condition as poor as that of the aforementioned shaley soils, or even worse. In the Algonquin lake bed there are also heavy clay soils which, because of poor drainage, may frequently have poor physical condition.

Stoniness

Any considerable number of stones in a soil detracts from its value, because of the obnoxious way in which they impede the process of cultivation, indeed, there are areas where excessive stoniness prevents the use of sites which otherwise possess very favourable soils. The relative stoniness in various parts of the region is shown in Fig. 5 in which there is an attempt made, by means of the number and size of the dots, to depict the character of the stones as well as the number present. The stoniest soils are found on the limestone moraines in the northeast, and on the "boulder pavements" along the shorelines of Lakes Algonquin and Iroquois. Irregular pieces of limestone are common to the moraines, and rounded Archaean boulders to the shorelines, but in both cases much of the land is left uncleared either as woods or rough pasture. The soil on the drumlins, especial in parts of Peterboro, Northumberland and Hastings, may be excessively stony although most of it is cleared where the topography is at all favourable. In the northern uplands of Simcoe county there are also some very stony places.

The lacustrine soils are generally quite free from stones although occasionally erratics occur. The soils developed on the ground moraine of the Ontario ice lobe are also fairly free from stones, the shaly group in York, Peel and Halton counties are particularly favoured because of the soft nature of the rocks from which the till was derived.

Chemical Characteristics

Having discussed the chief physical properties of these soils, it remains to describe the chemical characteristics. Since these involve the results of various soil tests the procedure and methods used are of interest and will therefore briefly be considered.

During the course of the field work a series of samples was taken from each of the more prevalent types of soil which were identified. In order that these samples might be representative of cultivated land which had received no special treatment they were usually taken from hay or pasture fields, although occasional samples were taken from grain fields. Actually about 75% of them came from alfalfa fields. A small proportion of the tests were made on freshly collected samples in the field but most of them were air-dried and later tested in the laboratory.

Soil reaction was obtained by the use of indicators, chiefly brom-thymol-blue and brom-cresol-green in their respective pH ranges. Carbonates were graded roughly according to the amount of effervescence produced by weak hydrochloric acid. The Spurway (Simplex) tests (6) were made for nitrates, phosphorus, potash, calcium and magnesium; easily replaceable potash was determined in a neutral, normal sodium chloride extract, shaking for five minutes but proceeding otherwise as in the Spurway system. It was found highly desirable to read the potash tests before a uniform white light against a shiny black background, using prepared standards for comparison. Easily replaceable calcium and magnesium were determined in the same extract and the data used to supplement the results of the Spurway tests. Finally, the easily soluble phosphorus was extracted with a $KHSO_4$ solution at a pH of 2.0 using a soil to solution ratio of 1 : 14, the phosphorus content being graded as in the Lamotte-Truog field tests (3). In all, over 750 samples were tested, 70 being from the most extensive type of soil encountered, and correspondingly fewer from those less important. The data obtained from these tests have been incorporated in a series of charts similar to those of the physical characteristics. In this way a general idea of the natural fertility levels in the various districts is obtained and may be used as a guide to lime requirements and fertilizer needs of the various soils. Figure 6 shows the locations from which the soil samples were collected.

Reaction

The first factor to be considered is reaction. Not only is it the best single index of lime requirement but it is correlated with many other properties that affect crop adaptation. The approximate pH values of the surface soil of cultivated fields in the various localities is indicated in Figure 7.

It has been stated already that the region contains an unusually large area of alkaline soil. The calcareous clay loams and the marly soils have a reaction above pH 8.0 which according to McGeorge (4) is the critical

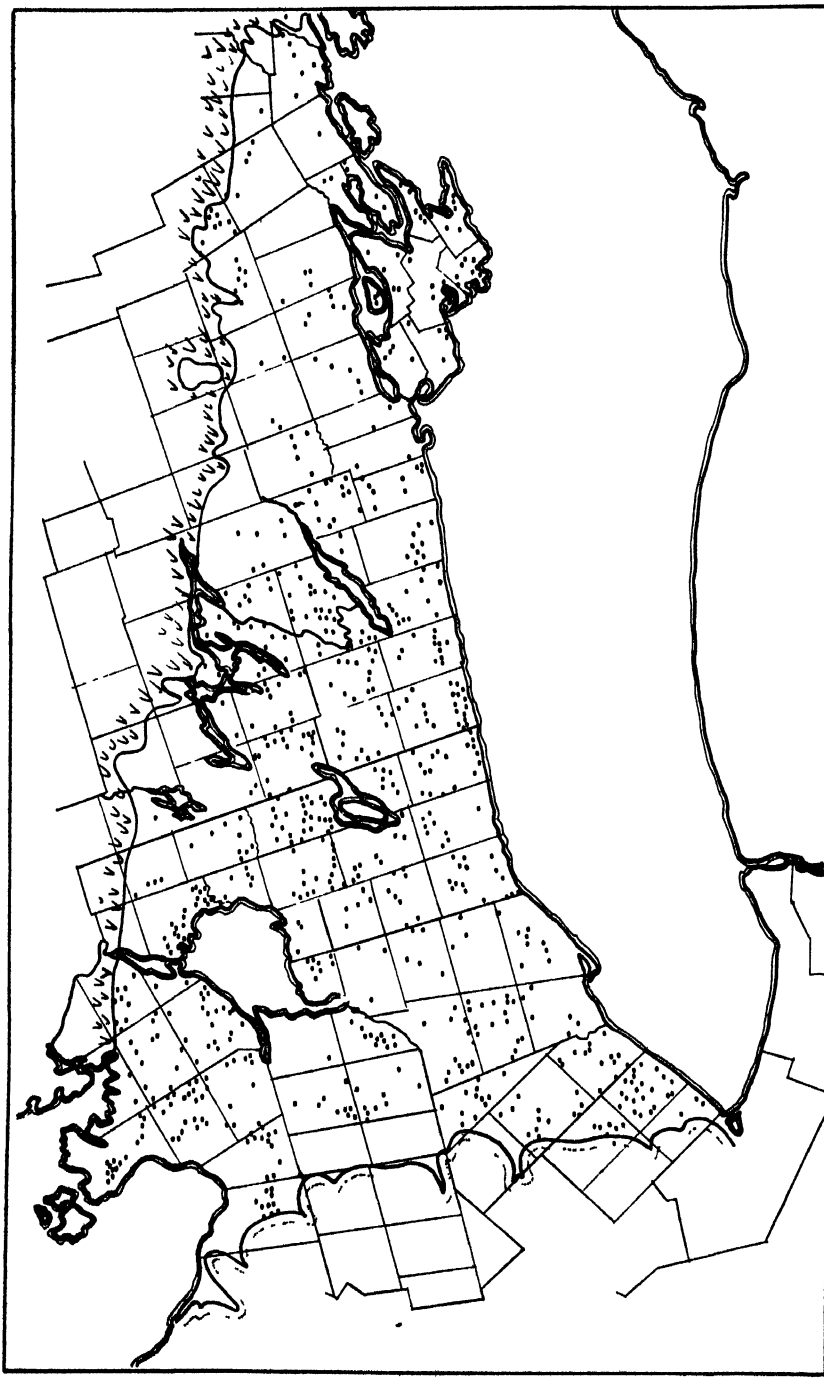

FIGURE 6. Location of soil samples.

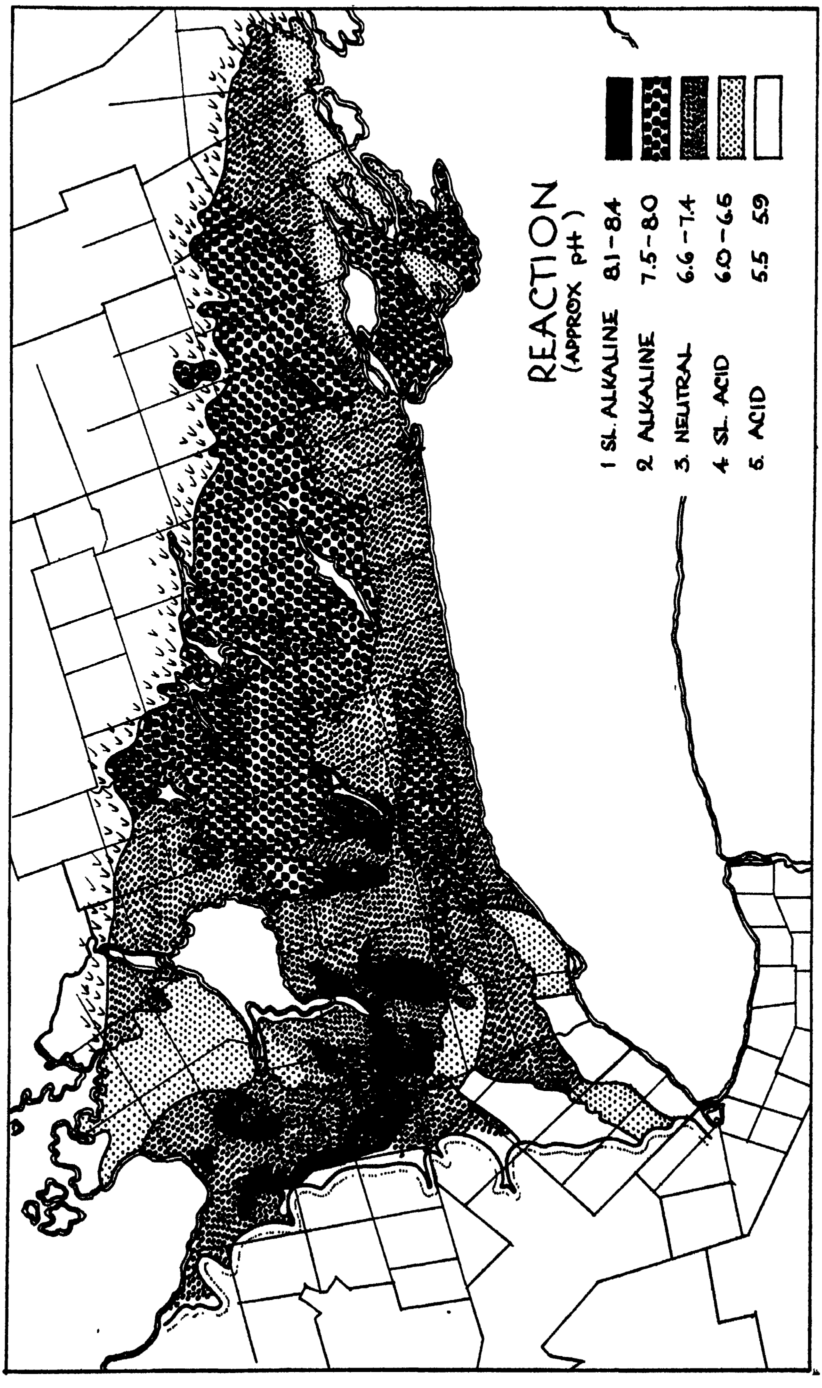

FIGURE 7. The reaction of the surface soil in cultivated fields.

limit for phosphate solubility in alkaline soils. The stony loams on the limestone till, and the calcareous, poorly drained, fine sandy loams have a reaction lying, for the most part, between pH 8.0 and pH 7.5, while there is a very large area of soils of various textures having a circumneutral reaction (pH 6.5–7.5). The area outlined on the map includes scattered areas of calcareous soil, such as eroded places which have a pH value above 7.5 and, on the other hand, many spots in the coarse sandy soils of the Interlobate area may have a reaction below pH 6.5. The clay loam in the Napanee plain, the light loam on the Simcoe uplands, and some of the mixed limestone and shale soils found chiefly in Scarboro and King townships are only mildly acid (pH 6.0–6.5). The most acid soils are those developed on the shaly drift in Peel and Halton counties, where most of the soils are about pH 5.5 while some samples possess values as low as 4.5.

Carbonates

Figure 8 is a map showing the incidence and relative amounts of free carbonates in the surface soil, as indicated by effervescence with dilute acid. Some of the free limestone now found in the plowed layer was present in the original surface horizon of the virgin soil, some of it is the result of erosion and washing, and the rest from plowing up the subsoil. Earthworm casts on the surface are sometimes highly calcareous. In the case of poorly drained soils, most of the carbonates were present in the virgin surface; in the case of the calcareous clay loams all the above factors may contribute; while in the case of the stony loams, perhaps most of the limestone has been plowed up owing to the shallowness of the profile.

The marly soils in Simcoe county near the Minesing Swamp and Marl Lake have a high carbonate content, the surface frequently having a white colour due to the presence of the marl. In the second class, where a strong effervescence with acid is indicated, the Schomberg clay loam is known to have a carbonate content of from 2 to 4% (expressed as $CaCO_3$ equivalents) in uneroded locations, while the soils of the third class will have lesser amounts. In the third class, carbonates are found only infrequently. All told, it will be seen that over one-third of the area is calcareous, somewhat less than a quarter has soil which is acid in reaction, while the remainder has soil which is nearly neutral in reaction and may or may not have traces of free carbonates on the surface.

Available Calcium

In Figure 9 are shown the levels of the easily soluble calcium in the surface soil. The available calcium is correlated with reaction modified by texture, heavy soils being better supplied than those of a more sandy nature having the same pH values. Hence the lowest levels are found in the sandy soils of the Interlobate area, although the reaction of most of the samples was near the neutral point. Similarly the sandy soils of the Algonquin plain are as low in available calcium as the loams of the Simcoe uplands or the much more acid clay loams in Halton County.

Available Magnesium

Magnesium is less abundant than calcium in the soil, and while in some instances, deficiencies occur demanding the use of dolomitic limestone, no definite cases of magnesium deficiency have been seen in this

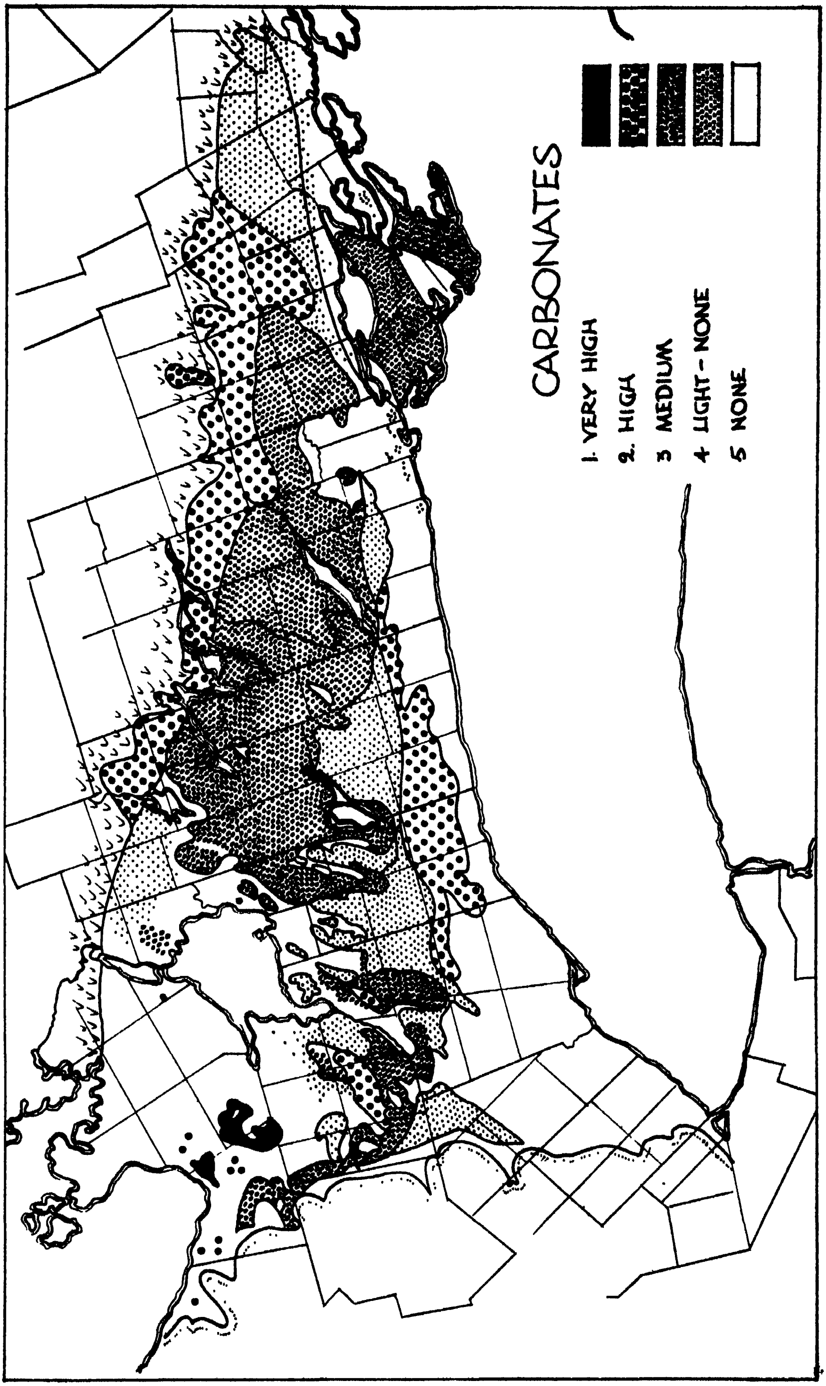

FIGURE 8. The relative amounts of free carbonates in the surface soil of cultivated fields.

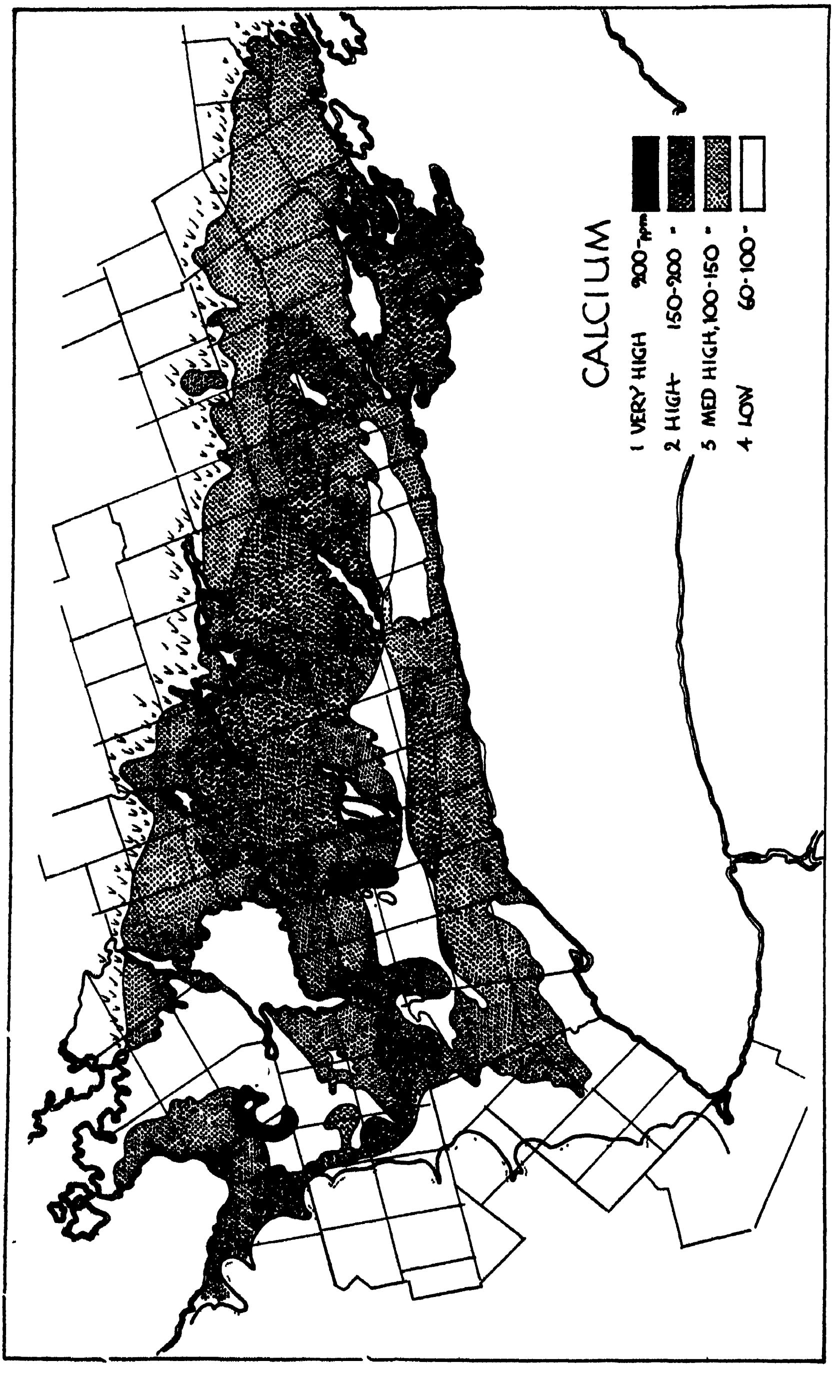

FIGURE 9. The easily soluble calcium levels in the soil.

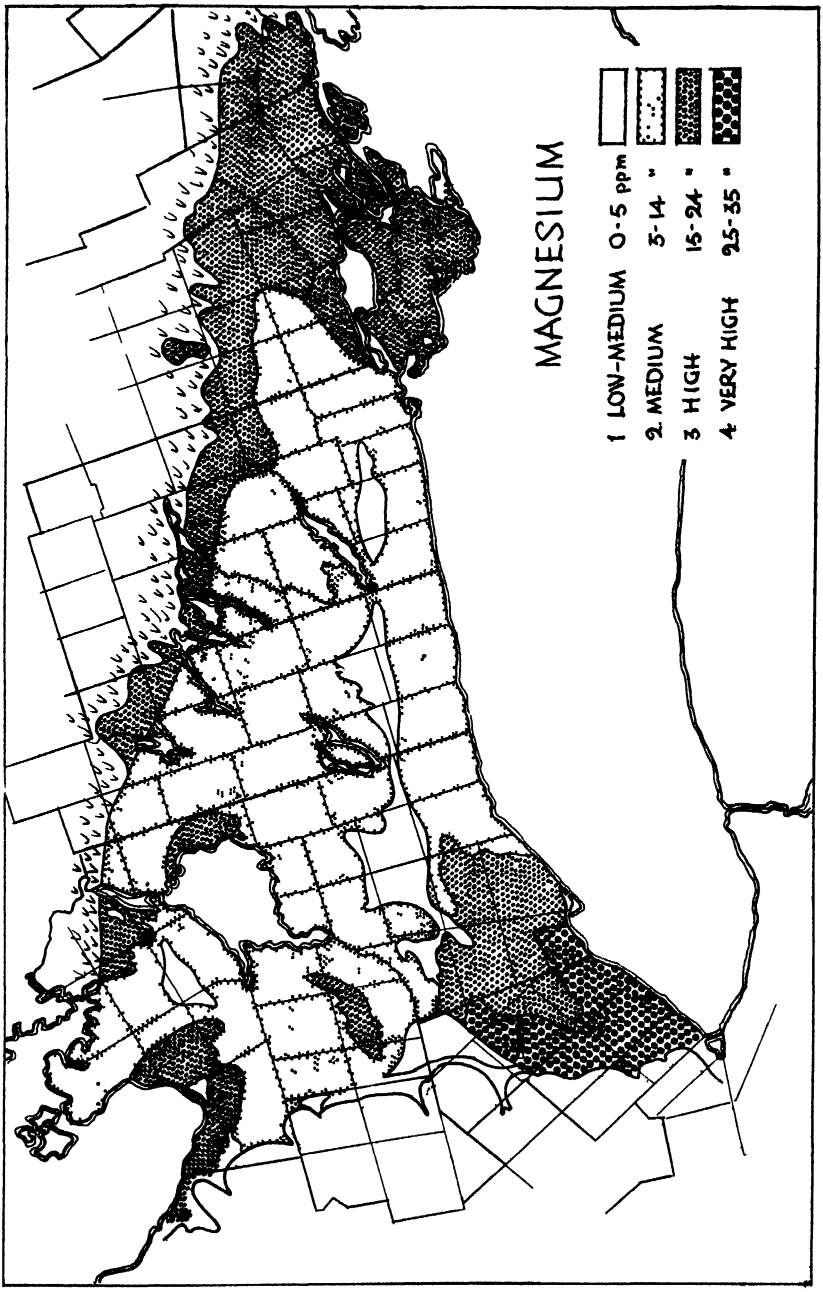

FIGURE 10 The easily replaceable magnesium levels in the soil

region. However, the levels in some of the soils are quite low, and especially is this true of the sandy soils of the Interlobate area. It is a peculiar fact that the most acid group of soils, the shaly soils, have the highest content of available magnesium, much higher than that of the broad areas of calcareous soil. The low magnesium levels unquestionably reflect the calcitic nature of the parent limestones. Figure 10 shows the comparative distribution of easily replaceable magnesium in the soils of the region.

Available Nitrogen

The amount of nitrate nitrogen in a soil varies widely with the seasonal conditions and other factors such as uptake by growing crops; therefore a single test is of doubtful value as an index of the available nitrogen in a soil. Moreover, the degree of dark green colour in the foliage is so closely indicative of the supply available to the plant that it is not so necessary to test for this element. Therefore, although all the samples were tested for available nitrates, it has not been thought advisable to present the data in the form of a chart.

Available Phosphorus

It should be stated at the outset that, without exception, all the soils in south-central Ontario are low in available phosphorus. Nevertheless, there is considerable variation in this respect, and the soils have been classified into three divisions according to their relative levels, as shown in Figure 11. The data for this chart were obtained from the results of the $KHSO_4$ extraction method, although there was found to be a fair degree of correlation between it and the Spurway test.

In general it would seem that this element is most abundant in the sandy soils and more likely to be deficient in the heavy clays, but, beyond this, there seems to be an interesting correlation with geological material. The light loams and sandy loams of the northern part of Simcoe county, where the till is composed largely of Archaean materials, are quite deficient for soils of such texture and reaction. The shaly soils of Halton and Peel counties have the lowest supply of all. On the other hand, the heavy soil on the marine clay in the eastern section is fairly well supplied. While some of the very alkaline soils, above pH 8.00, particularly the calcareous clay loams, are deficient due to the lack of availability, the fact should be stressed that there are large tracts of fine sandy loams, loams and stony loams which have calcareous plow soils that contain average or better than average amounts of easily soluble phosphorus.

Available Potassium

The general distribution of the various levels of available potash is indicated in Figure 12. Here again there is a definite correlation with texture but the relationship is the reverse of that shown in the case of available phosphorus. The sandy soils, without exception among the samples tested, were low in potash; the loams tend to be in the medium class and the clay loams are well supplied. The influence of geological material is also evident: the loams derived from Archaean drift are higher in available potash than similar textured soils on the limestone till, while among the heavier soils, those developed on the shales are most abundantly supplied. In fact the shaly soils have the best supply of potash of any of the soils in the region.

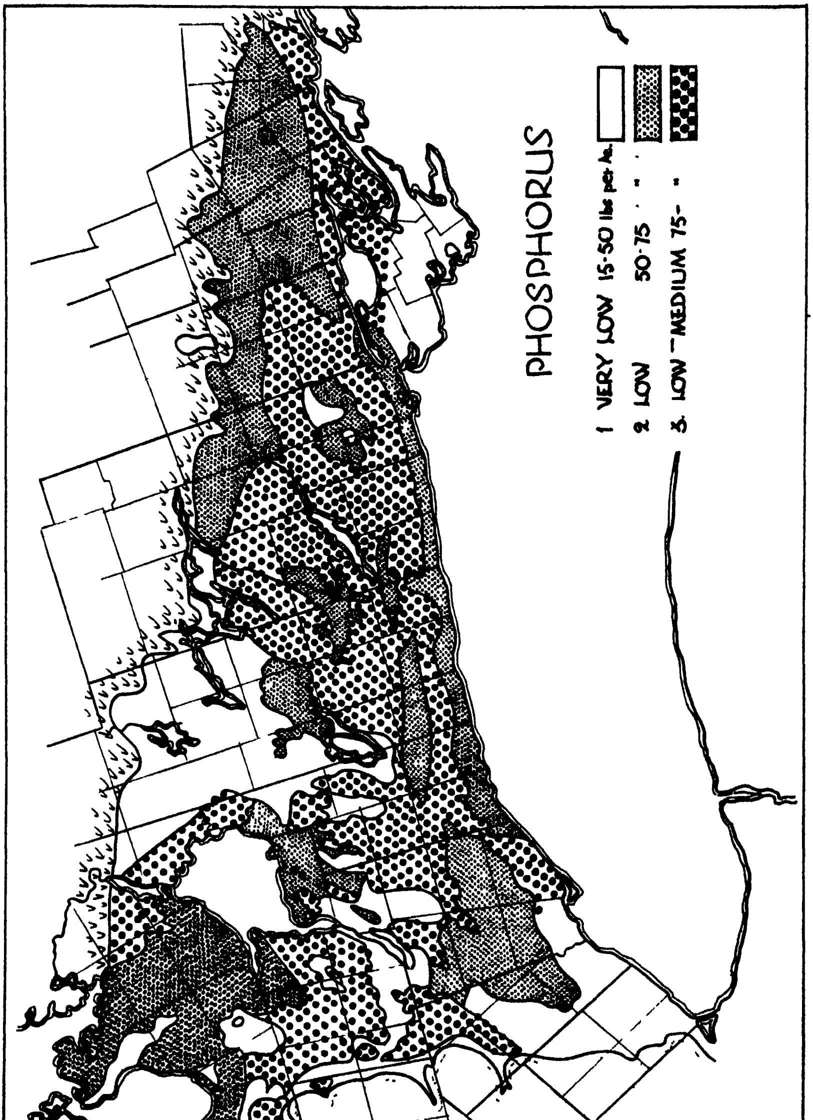

FIGURE 11. The relative amounts of available phosphorus in the soil.

Organic Matter

While at the present time there is not sufficient data available upon which to construct a chart of organic matter content, it is possible to point out some observed differences. Apart from the organic soils, which are fairly abundant, those with the highest organic matter content are the poorly drained, alkaline soils, which are found fairly extensively in the Algonquin Lake plain. The clay loam of the Peel plain is above the average in this respect, the organic horizon of the virgin soil being fairly thick. This is in sharp contrast to the adjacent shaley soils which had very thin surface horizons and consequently are quite low in organic matter. From general appearances it would seem that the soils with the lowest levels of organic matter are the sandy soils of the interlobate moraine and similar areas of coarse sand and gravel.

Fertilizer Requirements

The object in making soil tests for the various chemical constituents is, needless to say, to provide a basis for rational recommendations as to the fertilizer requirements of the various crops on the different soils. It is obvious that the day of blanket recommendations is long past, and while there is no substitute for properly controlled fertilizer tests with each crop to be grown to the various types of soil, it is felt that a survey of the natural fertility of the areas concerned should be a valuable aid both in the planning of such experiments and in the formulation of interim recommendations.

From the fact that alkaline and calcareous soils are found over so large an area it can be seen that in those areas, at least, there is no problem of lime requirement. In such cases the futility of adding more ground limestone is evident; moreover, because of its tendency to increase the pH to a point where soluble phosphates are converted to the carbonato-apatite form, which is relatively insoluble and hence unavailable to plants, it may even be detrimental. This is also true of the limestone used as filler in commercial fertilizers.

On the other hand, almost a quarter of the area is occupied by acid soils. Some of these soils produce good crops of alfalfa and clover without any special treatment probably because there is an abundance of lime in the subsoil at a comparatively shallow depth. Even though only mildly acid, and containing medium amounts of soluble calcium and magnesium, the soil on the marine clay responds markedly to liming, because it has a greater depth of acid soil and very little free carbonate in the subsoil. Most of the acid soils should respond to applications of ground limestone, either the calcitic or dolomitic type being suitable for heavy soils, but the dolomitic being preferable in the case of sandy soils.

Throughout the area phosphorus is required, and fertilizers having high amounts of phosphate should be used; in fact, in many cases superphosphate alone is the most economical commercial fertilizer to apply.

It is believed that the results of soil tests are a fairly reliable guide as to the widom of applying potassic fertilizers. Those soils which are in the lowest class (Figure 12) are definitely in need of potash, and symptoms of potash deficiency have been observed in certain crops grown in those areas; hence a high proportion of the element in question should be present in all fertilizer used. Those in the next class, having 20–30 p.p.m. in the

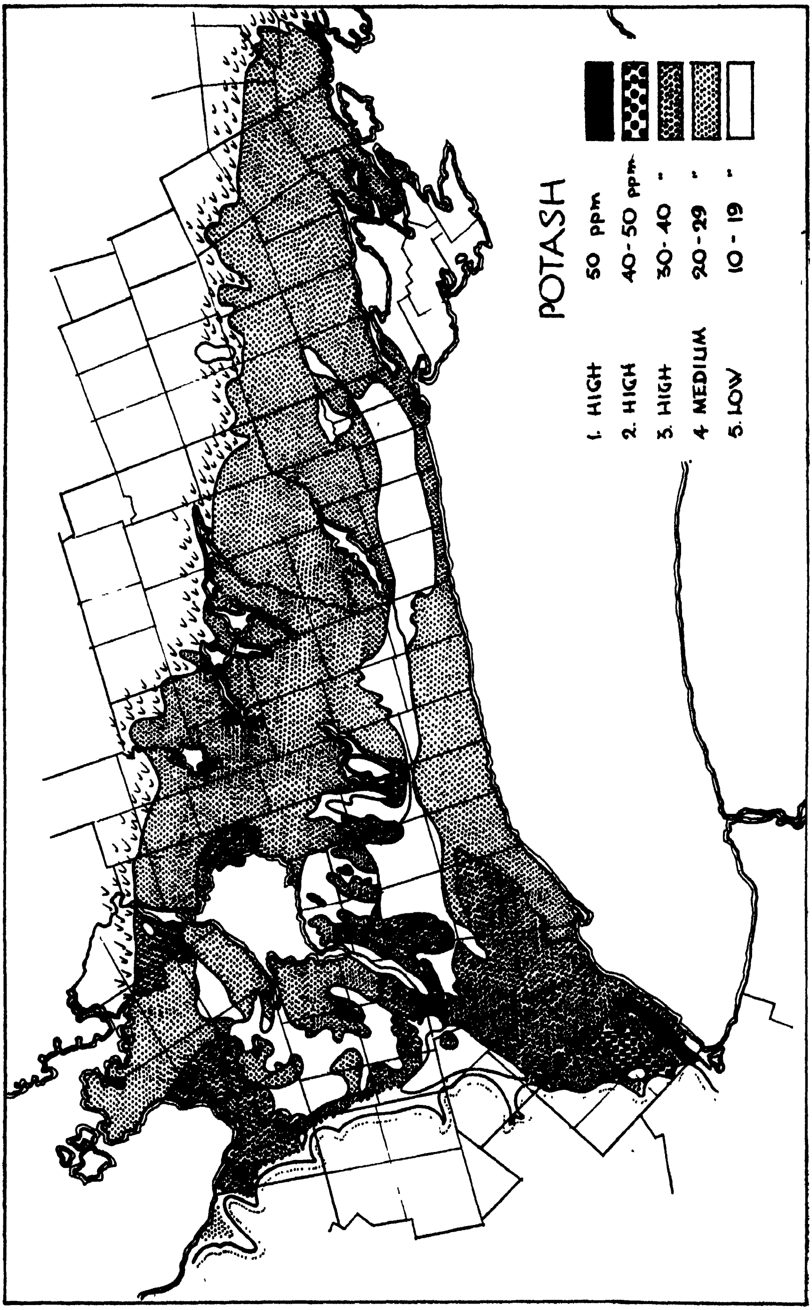

FIGURE 12. The levels of easily replaceable (avialable) potash in the soil.

extract, or from 160 to 240 pounds per acre of easily replaceable potash in the soil, are in a median group, which is still in need, but requires lesser applications of potassic fertilizer. However, when the soil contains higher levels than this, it is doubtful if potash will benefit the general run of farm crops, especially since these lands are invariably the ones which are most deficient in phosphorus.

It must be understood that, at present, the results of rapid soil tests can serve as the basis of tentative recommendations only; for while they do give an accurate measure of the relative levels of the various available nutrients in the soil, there is as yet no comparative standard of requirements for each individual crop. This handicap, of course attends practically all methds of soil analysis, and it is to be hoped that the students of plant nutrition will rapidly accumulate the necessary information.

Natural Vegetation

It has long been noted by ecologists and plant geographers that certain types of vegetation are associated with certain kinds of soil, or better, that the vegetation is more or less influenced by edaphic or soil factors. On the other hand, it is also well established that the character of the vegetation has a direct effect upon the process of weathering taking place in the soil. It is, therefore, highly important that any survey of soil characteristics also include an account of the natural vegetation.

It is not easy to reconstruct a complete picture of the original forest cover because most of the land is now cleared, and those small areas which remain have been culled to a great extent. The most difficulty is encountered on the best soils for here the area left in bush is least. From a series of notes made throughout the area, however, the map shown in Fig. 13 was constructed. In it, an attempt is made to indicate the chief associations. There are, of course, a great many more species to be found in every locality than those mentioned, the object being to list only those which predominate and therefore should be characteristic of the type of soil.

On the hilly, droughty sands of the Interlobate Area white and red pines, red oak and sumachs are common. Equally typical are the red cedar and juniper of the dry flat limestone lands, together with the mulleins and blueweed of the clearings and pastures. Where sufficient moisture is present, white cedar is also plentiful on the shallow limestone soils.

The limestone till soils support a growth of mixed hardwoods and conifers; sugar maple, ironwood, beech, basswood, white pine, hemlock and white cedar being present, but in varying proportions. Along the fences, thickets of prickly ash or toothache tree (*Xanthoxylum americanum* Mill.) are common, as is also the wild grape. The acid upland soils of North Simcoe favour beech and hemlock, but sugar maple and white pine are also common. The shaley till soils of the southwestern part of the area are typified by a tree growth consisting of white, red and scarlet oaks, hickory and sugar maple. While few pines are left today it can easily be seen from the stump fences that this was originally a white pine country not only on the loams but on the clay soils as well.

In consideration of the vegetation on the plains of the old glacial lakes, it is well to note that as a rule the soils are less well drained than those developed on till. In the Algonquin bed, the well drained sands

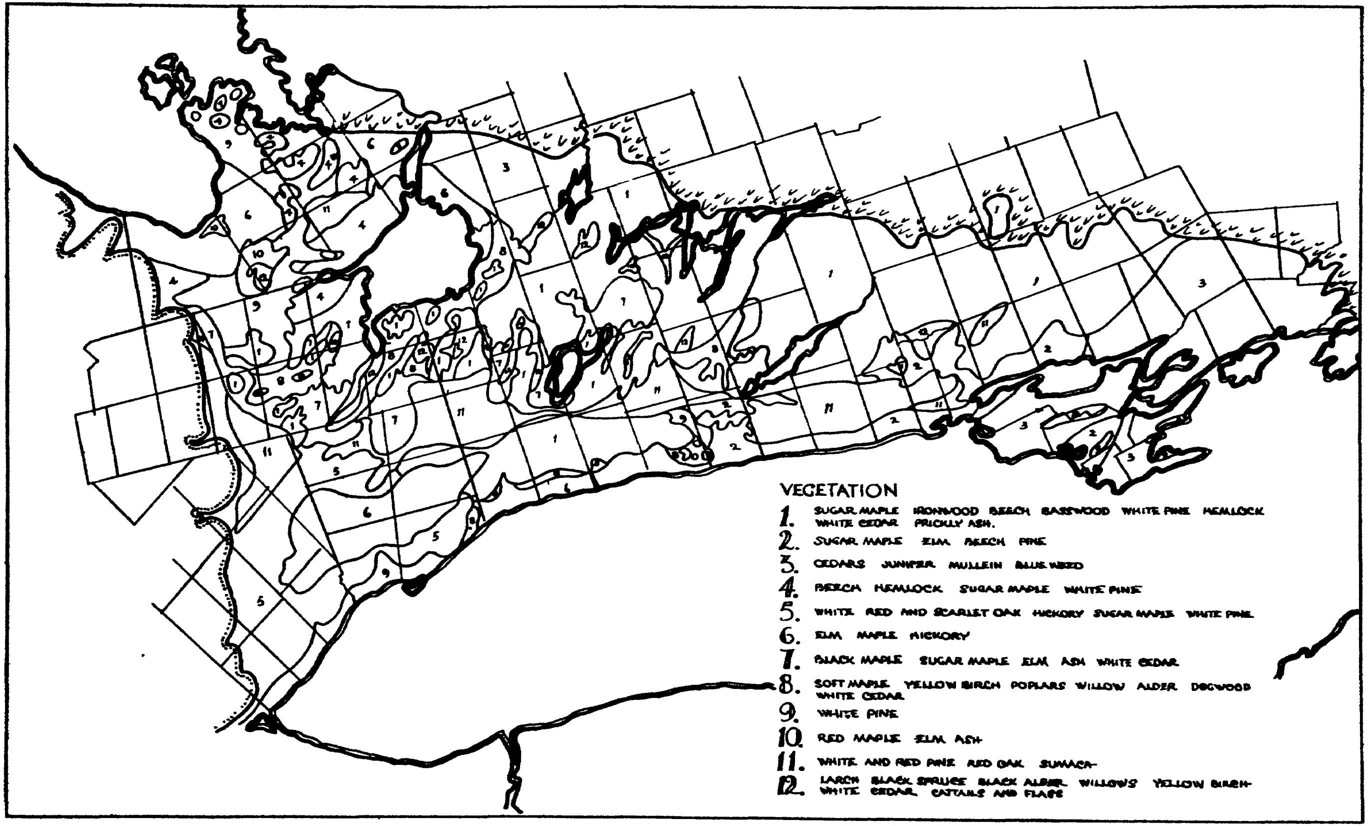

FIGURE 13. The dominant natural tree growth over the area.

and sandy loams of both the Natawasaga Valley and the Penetanguishene Peninsula were originally covered with solid white pine forests, the "Pine Plains" of other days. It is encouraging to note that some of these areas have been reforested and it is to be hoped that a great deal more will be done. Less well drained sands and loams carry soft maples, yellow birch, poplars, willows, alders, dogwood and, in the more alkaline areas, white cedars. On the poorly drained drab coloured clays which are common in the northern lowlands the chief forest trees are elms, ash and maples; the same sort of vegetation prevails on the marly soils near Minesing, red maple predominating.

In the Iroquois plain the good loam soil of Northumberland and Durham counties probably developed under a forest of sugar maple, beech, elm and pine. The lighter sands and loams carried pine forests while the clays supported elm, ash, and maple with little intermixture of soft woods. The wetter spots in the clay, as well as the undrained boulder pavements are characterized by cedar swamps. On the calcareous clay soils of the Schomberg plain, the black maple *(Acer nigrum)* is more common than elsewhere, while sugar maple, elm, ash and white cedar are also present. On the Peel plain elm, sugar maple and hickory are the prevailing trees.

Marshy soils are common in the northern part of the region, and carry several characteristic types of vegetation. Several small sphagnum bogs occur with the typical treeless association of sphagnum moss, high bush cranberry, leatherleaf and Labrador tea. Very wet locations, such as the Holland marsh in its undrained state, have sedges, cattails and flags. Many other areas with wet organic soils of varying depth are characterized by larch, black spruce, white cedar, yellow birch, black alder and willows.

Land Types

It has been previously stated that there are, relatively, a large number of soil types in the region, if the classification is done strictly on a profile basis, many of which are not encountered elsewhere in the province. By grouping those types which show similar profile development, and, to a large extent, similar topography, drainage and other physical characteristics; and by omitting some of the less extensive and less important types; it has been possible to account for most of the thirty or forty types of soil within thirteen major groups or land types. While to a large extent physical factors have been stressed, chemical characteristics are also discussed. The map in Figure 14 outlines the main areas occupied by each of the land types. It is natural of course, that this map should bear a fairly strong resemblance to that of the physiographic regions, given in a former publication (5). It will be seen, however, that physiographic regions may include several land types, and that the same land type may occur in more than one physiographic region.

In the following descriptions, the chief characteristics of each of the land types are embodied; but it will be noted that the poorer areas, such as the very wet soils, for instance, have not been studied in the same detail as have those areas of better soils which have been more extensively cleared and cultivated.

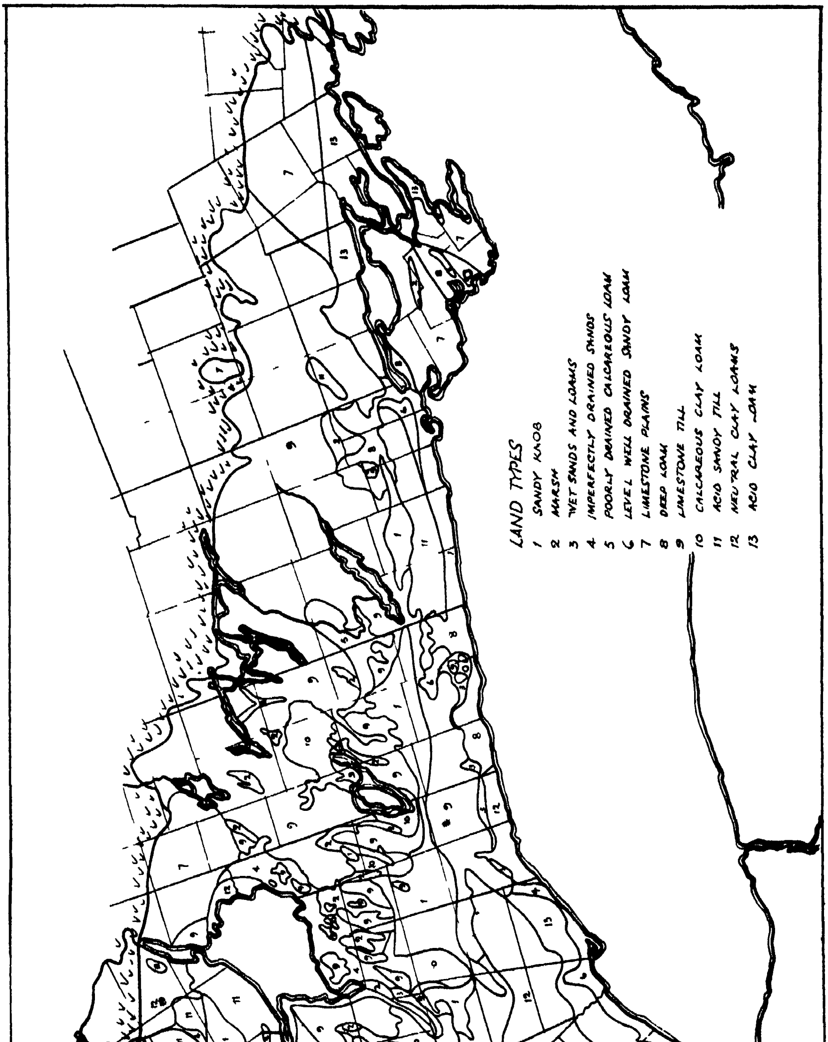

FIGURE 14. A chart of the larger areas of the different land types.

The Sandy Knob Type

This type includes the hilly, droughty, sandy soils commonly found on the sandy moraines and eskers. With these may also be classed the small areas of dune sands found on the shores of Georgian Bay and Lake Ontario. The area occupied is about 350,000 acres.

The profile development over much of the area resembles that of the Oshtemo type. There is a very shallow surface layer, a deeper, greyish-yellow "A_2" and a thin, medium-brown "B" horizon, which fluctuates greatly in depth, dips or tongues reaching down to 8 or 10 feet below the surface in extreme cases (Figure 15). It is common to find a double surface horizon caused by wind-blown sand having been deposited on the original surface which usually contains considerable charcoal. It is related that, before the advent of the white man, the Indians burned the pine forests off the ridges in order to facilitate the hunting of deer. In some of the more nearly level areas, finer sands occur, and here good soils of the Fox type are found. On the steeper hillsides there is a good deal of gullying and large blowouts are common. In many places there are knobs of boulder clay. The profile development of the dune sands is usually of the Bridgman type.

The surface horizon of the undisturbed profile is usually acid. Where a double surface layer is found it is neutral to slightly alkaline while in the blowouts and eroded spots it is, of course, calcareous.

The original vegetation was largely pine and oak forests with inclusions of maple and other hardwoods. Sumachs are common in waste areas and along the edges of clearings. In spite of its rough topography and poor sandy soils most of the interlobate area was at one time cleared and farmed, but much of it is now abandoned or used for sheep pasture only. Among the commonest grown crops are rye and sweet clover. Potatoes are locally considered to be a well adapted crop, while winter wheat is grown to a limited extent. Some years ago a number of poultry farms were established in various districts but most of them are now abandoned. In reality there are only relatively small areas that are capable of supporting farms.

Quite large acreages have been reforested. The Northumberland Forest, in the township of Haldimand was established in 1924 and enlarged to 1000 acres in 1931. Somewhat smaller reserves are located in Manvers township and elsewhere. These pine plantations present a splendid contrast to the barren wastes nearby which should also be replanted; for, without doubt, reforestation is the optimum use to which such land can be put.

The Marshy Type

Because of the irregular and scattered character of the distribution of the muck and peat deposits, they cannot be completely represented on the map. The larger areas, however, are indicated, and since most of the smaller patches occur in the same vicinities, chiefly in the more northerly sections, the regional distribution is fairly well shown. In this land type are included all kinds of very wet organic soil, of which, as yet, very little has been improved, the largest and best known development being that of the Holland Marsh near Bradford.

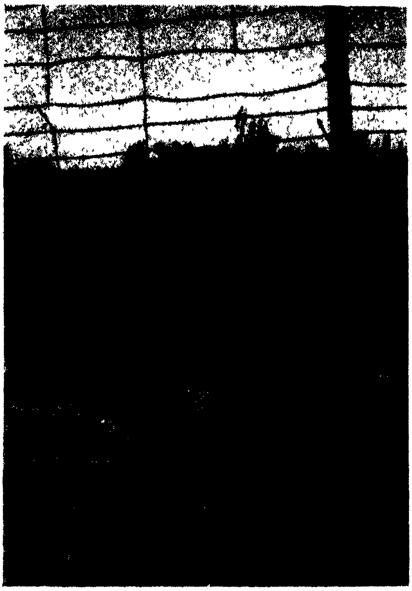

FIGURE 15. The sort of soil profile commonly found within the sandy knob type.

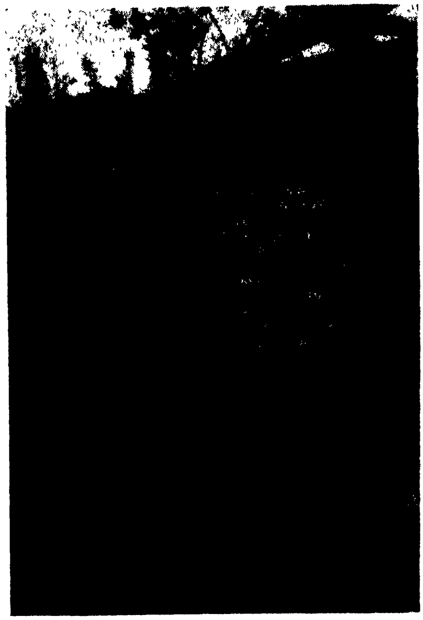

FIGURE 16. A profile of a poorly drained calcareous fine sandy loam.

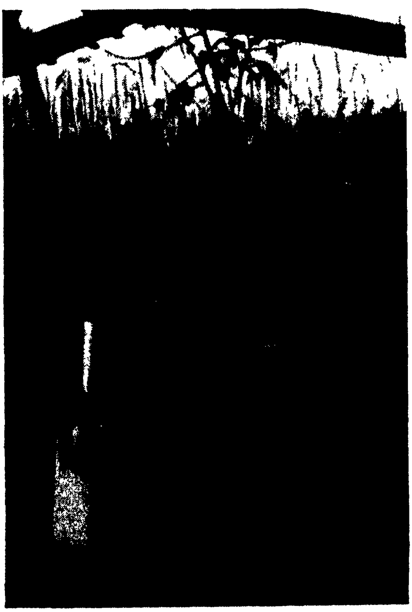

FIGURE 17. Showing the "nodular" character of the upper rock strata, a condition common in Prince Edward county.

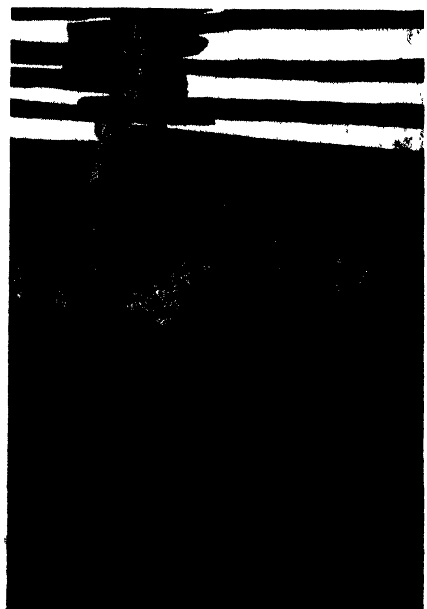

FIGURE 18. A soil profile common to the deep loam type.

The factors which govern the suitability of these soils for the growth of truck crops are too involved for discussion here but one of the chief drawbacks is the prevalence of fall frosts in these low-lying areas.

The Wet Sands and Loams Type

In this category belong all mineral soils, whether sands, loams or stony loams, which are very poorly drained. Patches of muck are inevitably associated, while the vegetation consists chiefly of white cedar, black alder, willow, elm and soft maple. Such soils are very commonly found just inside the beach lines of the extinct lakes, while those sections where there is a shallow and irregular covering of drift over the bedrock also include considerable areas. The usual profile consists of a highly organic surface horizon, underlain by grey and rusty mottled subsoils.

Very little of this type of land has been improved since it is usually stony or shallow, and at present does not justify the rather difficult task of draining and clearing.

The Imperfectly Drained Sands Type

These sands are all of lacustrine origin and usually quite level. The largest areas are found along the margins of the Algonquin lake plain in the northern part of York and Simcoe counties. The chief soil components of this land type are members of the Berrien, Rubicon, Saugatuck and Allendale series. The profile varies from that of a mature podsol with a shallow ashy grey horizon and dark brown, slightly indurated hardpan layer, to cases in which a somewhat organic surface horizon directly overlies a yellow mottled subsoil. Frequently clay or rock occurs within a few feet of the surface. They are poor sandy soils with bad internal drainage, usually acid in reaction and low in fertility elements.

Over much of the area the original tree growth was chiefly white pine, but, on some of the more poorly drained phases, yellow birch, aspen, soft maple and alders are found while brake ferns abound in the clearings.

In the north and east a large proportion of this land is unimproved, but where it occurs in the more specialized areas such as the lakeshore district between Toronto and Hamilton, such soil is usually underdrained, improved and used in the production of a wide variety of fruit and truck crops.

The Poorly Drained Calcareous Loam Type

The bulk of this land is found in the Algonquin lake plain, but smaller areas appear wherever lacustrine deposits of limestone origin are found. The topography is flat and both surface and internal drainage is poor; the texture varies from loam to fine sandy loam. The total area is about 150,000 acres, much of which is found in Tecumseh township but smaller areas occur throughout the Algonquin lake plain and also south of Peterborough and near Brighton in the Iroquois lake plain.

In most of the areas mentioned, a single characteristic type of profile development occurs. It consists of a very dark surface horizon, some six or seven inches deep, over a yellow and grey mottled subsoil of fine sand or silt. A typical example is shown in Figure 16.

It is an alkaline soil with a pH of 7.50–8.00, having free carbonates in the surface and throughout the profile. Low available potash, and low to medium phosphorus levels are typical.

Silver maple, poplars, elm, yellow birch, white cedar and alder are the most commonly associated trees, while in the clearings and fence rows, goldenrod, sensitive fern and impatience are abundant.

Much of this land is still in an unimproved state. The factor which limits its value is drainage, very little artificial drainage having been installed because of the lack of good outlets in such widespread level areas. If thoroughly drained and properly fertilized, these soils would be excellent for a wide variety of farm crops, being high in organic matter, level, stoneless and easy to till. For most crops mixed fertilizers with a fairly high proportion of potash should be used.

The Level Well Drained Sandy Loam Type

These soils are also of lacustrine origin and are found on deltas and other well drained deposits in Lakes Algonquin and Iroquois. The chief areas in which they occur are located near Alliston, Creemore, and Lafontaine in Simcoe County while smaller patches occur between Toronto and Hamilton. The total area of this land type is estimated to be 150,000 acres.

In the main, there are three distinct soil types in this group which in their profile development bear a strong resemblance to the widespread Fox series. The surface horizon is usually a brownish grey sandy loam over a deep stratified sand, fine sand or gravel subsoil. Where the subsoil is very open, there are small areas of Plainfield type, but the better soils usually contain enough material of the finer particle sizes in their subsoils to cause the development of a brown "B" layer, several inches in thickness. These soils are all acid in reaction, some more so than others. Near Alliston the surface soil usually has a reaction of pH 6.00–7.00, while near Lafontaine and in the district between Toronto and Hamilton it is slightly more acid. They are usually fairly well supplied with soluble calcium and have a medium amount of phosphorus but are low in available potash.

Solid white pine forests originally covered these areas, and in many localities stump fences are still numerous.

The agricultural development of these soils depends largely upon their location since as a rule they are fairly adaptable. In Simcoe county all the common farm crops are grown successfully except on the lightest phases, while near Alliston there is considerable specialization towards potato culture. In the district between Hamilton and Toronto these soils are in keen demand for orchards and market gardens.

The Limestone Plains Type

In the Napanee plain, and in the northern parts of Ontario and Victoria counties, there are altogether about 600,000 acres, where the soil consists of a very thin deposit over flat, stratified, limestone bedrock. In Ontario and Victoria counties the rock is almost bare over large areas, while in the Napanee area there is from six inches to a foot of either limestone till or water-laid clay. In Prince Edward County a peculiar condition exists. Some of the upper rock strata are "nodular", that is, the limestone layers readily break up into pieces not unlike coarse roadstone, while interbedded with these are thin layers of shale. The cracked limestone and weathered shale allows for somewhat deeper root penetration and creates a better soil than is usual on rock plains where the upper strata are more massive.

A typical example of type of soil, locally termed "clay gravel" is seen in Figure 17.

The associated vegetation is usually quite specific, cedars, juniper, mullein, blueweed (*Echium vulgare*) and stonecrop being common everywhere. In some places there are stands of balsam fir, while if the soil is slightly deeper than ordinary, elm and rock maple may occur.

The predominant agricultural use for this type of land is pasture, the chief forage plant being Canada blue grass, although in some places white Dutch clover is fairly abundant. In the deeper phases, where there is a foot or so of soil, hay, grain and corn are grown with fair succession some seasons. In Prince Edward County the better phase (clay gravel) is used for farm crops, corn, sweet clover and alfalfa doing very well. It is utilized for canning crops such as peas and tomatoes, and also for apples, although it cannot be considered to be well adapted to these crops.

The chief drawback to agriculture on these soils is the extreme drouthiness, and it is an odd coincidence that this shallow soil should be situated in Prince Edward County which is one of the driest climatic zones in the province.

The Deep Loam Type

The best soils of lacustrine origin comprise the deep loam type which is most abundant in the Iroquois lake plain but is also found to a smaller extent in the beds of Lake Algonquin and some of the smaller glacial lakes. There are about 100,000 acres of this land located chiefly in the vicinities of Bowmanville, Newcastle, Port Hope, Codrington, Wooler, Norham Morganston and Plainville. The surface is a smooth, even textured, fine sandy loam to silty clay loam developed on deep beds of fine sand, silt and clay. The subsoil is often considerably heavier than the surface. The internal drainage is imperfect and much of the land has to be tile drained, especially when planted to orchards.

The profile is that of a typical grey-brown earth with considerable variation arising chiefly from the textural differences in the deposits. The profile development is shown in Figure 18.

The reaction in most cases is about neutral with plenty of available calcium. There is a medium amount of available potash and medium to low levels of available phosphorus.

It is a good soil and well adapted to most crops, including cereals, clovers, grasses, corn and roots. In some districts, canning crops, such as tomatoes, corn and peas, are grown.

One of the outstanding features of this land type has been its utilization for apple growing. The counties of Durham and Northumberland have for years been justly famous for their orchards, the best of which are always found on the good deep loams. The best orchards in Prince Edward County are also found on similar soil types.

The Limestone Till Type

This is by far the most extensive land type in the region comprising between 1,500,000 and 2,000,000 acres. It is almost coextensive with the drumlin belt and in addition includes some of the Ontario till plains. Much of the land in Peterborough, Victoria, Durham and Ontario counties is of this type, but every county in the region, except Peel and Halton, includes some of it. The topography is gently rolling to hilly, with some

hillsides too steep for cultivation. In some places the land is quite stony; drainage is good except for seepage spots on some hillsides.

There are five distinct soil types, all of them loams or stony loams. Four of the types have very shallow profiles, with a coffee-brown "B" layer occurring immediately under the furrow slice in cultivated fields, the fresh, grey limey till being usually within fifteen inches of the surface as seen in Figure 19. The other type has a somewhat deeper profile since it occurs on a more sandy till.

All these soils are alkaline with pH values from 7.0 to 8.5. In the first four types, free carbonates are found intermittently over the surface in virgin areas, but are fairly generally abundant in all plowed soils; in the fifth type they are intermittently found in cultivated fields, the reaction of this soil being usually about neutral. The levels of both available potash and available phosphoric acid are usually in the medium category and complete fertilizers are therefore the logical choice for most crops.

The predominant forest vegetation consists of hardwoods, sugar maple, beech, basswood, ironwood and elm being common, while on some types there may also be considerable intermixture of softwoods such as white pine and hemlock. On the most calcareous types prickly ash is abundant in the clearings and along the fences.

Apart from those spots which are too hilly or stony for cultivation, these are good soils for general agriculture, well adapted to winter wheat, alfalfa, oats, barley, clovers, roots and fodder corn. In Victoria County sweet clover and alsike are extensively grown for seed.

The Calcareous Clay Loam Type

In the general region of the limestone till soils, there are also fairly extensive deposits of highly calcareous lacustrine clays upon which important soil types have been developed. Althogether, this land type includes about 200,000 acres, the largest tract being the area of gently rolling and moderately well-drained soils in the Schomberg lake plains of York and Simcoe counties. Included also are the marly soils of the Minesing district as well as smaller areas of clay near Uxbridge, Port Perry, Lindsay, Bethany, Baileyboro and Trenton, some of which are more poorly drained.

The level areas require artificial drains, and even the rolling soils, where drainage is generally adequate, are greatly improved by putting tiles up the main hollows and into springy spots. Considering its heavy texture, the physical condition of the soil is good, even the subsoil being relatively porous.

The reaction is quite alkaline, usually ranging about pH 8.0–8.5, while free carbonates are fairly abundant on the surface in cultivated fields. The amount of available phosphorus is almost always deficient; available potash levels are fairly high; organic matter content, medium; while available nitrogen seems relatively high to judge from the appearance of the crops. In view of this, it is probably more economical to use superphosphate alone for winter wheat and other cereals. If the soil is not in good tilth, and has not recently been manured or grown a clover crop, some nitrogen is apt to be needed, and a complete fertilizer is to be preferred.

The forest growth includes black maple, rock maple, elm, ash, basswood and ironwood on the better drained lands, while red maple appears to dominate the marly types.

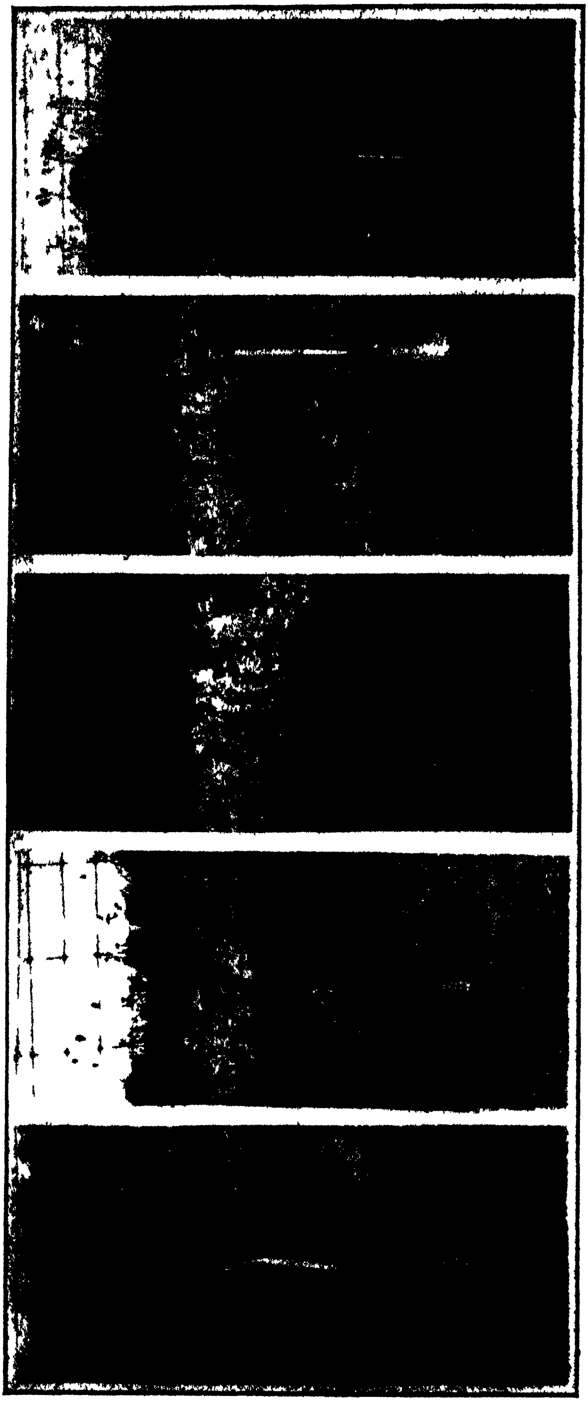

FIGURE 19 Profiles of the five limestone till soils.

This land has long been regarded as excellent for general farming and livestock raising. Winter wheat is intensively sown and produces good crops; and, except where the drainage is very poor, alfalfa and clovers do well.

The Acid Sandy Till Type

Two distinct soil types, covering about 250,000 acres, are included in this group. The first type is found on the Simcoe uplands where it is developed on a rather sandy till which is composed largely of Archaean material. The second type is found on the rather large drumlins in the southern part of Northumberland county where the usual boulder clay seems to have been buried to a depth of three or four feet by a lighter deposit. Both are well drained soils as a rule, often inclined to be stony, and in some places include slopes which are too steep for cultivation. The surface texture varies from a light loam to a sandy loam.

Both types are mildly acid and would probably benefit by the addition of ground limestone. The Simcoe County soil has better than average potash levels and a very low supply of available phosphorus, while the Northumberland County soil has about the highest phosphorus and lowest potash levels of any soil in the region.

Beech, pine and sugar maple are the predominant forest trees in both areas. Hemlock is fairly common in the northern part.

Neither of these soils can be considered as first class land but general farming can be fairly successful. A fair percentage is used for grazing. Alfalfa does not thrive in either location, its place being taken by red clover, while potatoes are a fairly well adapted crop, especially in Simcoe County.

The Neutral Clay Loam Type

All the level, or nearly level, clay loams with a reaction about the neutral point are included in this type, the total area being about 350,000 acres. The Peel Plain in Peel and York Counties comprises about half of it, the remainder being situated partly in the Iroquois Plain between Toronto and Bowmanville, and partly in the Algonquin Plain, notably near Elmvale and Beaverton.

Drainage may be quite good or poor depending upon the topography; tile drains are needed over much of the area.

The profile development resembles that of the Conover type, usually having a good horizonal development except where too poorly drained, when the subsoil is mottled grey and rusty brown. The surface soil is fairly deep and has a better than average content of organic matter. The soil in the Peel Plain has good physical condition, the crumb structure being especially noticeable in the spring. Lime is not required, and there is usually a good supply of available potash, but the level of available phosphorus is low.

The forest cover consists of rock maple, elm, ironwood, hickory, ash and basswood.

The heart of the noted alfalfa seed-producing section in Peel County is situated on this soil, but some other areas are too poorly drained to be ideal for alfalfa. Alsike clover does well and winter wheat can usually be depended upon. Spring sown grains are very largely grown; but corn and roots are not so well adapted, and potatoes do very poorly.

The Acid Clay Loam Type

There are between 500,000 and 600,000 acres of clay plains, usually with little or no relief, upon which acid soils have been developed. Some of these clays are lacustrine, but a large part of them were deposited as ground moraine. As a rule there are few stones to interfere with cultivation. The shaly soils of Halton, Peel and York counties make up the largest part of this land type, while to a much lesser extent it includes the acid clays of the Napanee plain and the old Algonquin Lake bed near Lake Simcoe.

The shaly soils include five distinct soil series: (1) the shallow red clay, (2) the flat clay loam of Halton county, (3) the red clay loam on the deeper till, (4) the rolling dull grey clay loam of Peel County, (5) the less acid till soils common to King and Scarboro townships. These soils all have a shallow surface horizon, a buff coloured "A_2" horizon of friable material and a rather compact "B" layer with a fair amount of depth, representative profile illustrations are shown in Figure 20. The first three soils are in many respects similar to soils which are fairly widely found in the Niagara Peninsula and probably constitute part of the same land type. The last mentioned soil is of distinctly better grade than the others, chiefly because of a much higher percentage of limestone material in the till and a much better natural drainage.

These soils are all acid with pH values varying from 4.5 to 6.5. They are high in available magnesium but low in soluble calcium, and with the doubtful exception of the last mentioned member, are definitely in need of lime. The shaly soils are extremely deficient in available phosphorus, but they have the highest levels of available potash to be found in the region. The amount of organic matter in the surface is low, the soils all being light in colour, fallow fields having a definite whitish cast when dry.

The natural vegetation consists of oak, pine, elm, hickory, beech, rock maple, ironwood and ash.

The profiles of the acid soils in the Napanee Plain and in the Lake Simcoe district have very drab colours and rather poor development; in the former case carbonates are not present in the subsoil which is very heavy and impervious, while the clay deposits upon which the latter soil is developed are calcareous. The surface soils are whitish when dry; poor drainage is the rule and the clay puddles and clods badly. These soils are only moderately supplied with phosphorus and potash and would benefit by the application of lime. The natural vegetation consists largely of elm, ash and maple.

With regard to agricultural adaptation there are three distinct subtypes in this land division. In the first is placed the slightly acid and better drained soils of King and Scarboro, and some of the grey shale soils. They are good general farming soils, spring grains and alfalfa do well but winter wheat is not extensively grown. Being near Toronto, dairying is the chief farm enterprise. The red shale soils are definitely inferior and need careful management. Lime and phosphate should be generously applied and the organic matter increased by the application of stable manure or the plowing under of green crops.

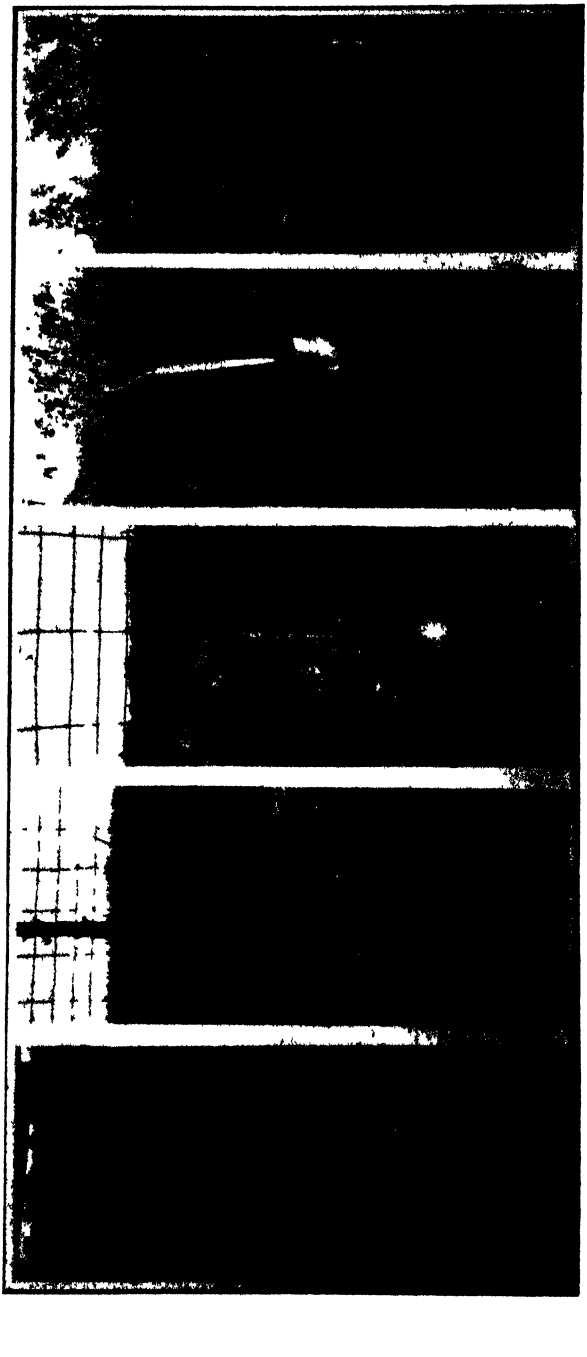

FIGURE 20. Profiles of the five shaly soils.

In the third sub-type, the heavy lacustrine clays, drainage is probably the first consideration. Good crops of clovers can be grown, especially when lime is applied, and in some cases alfalfa does well. Fertilizers containing both potash and phosphorus are to be recommended in most cases for general farm crops.

DISCUSSION

The physical features constitute the most implacable limits to the agricultural utilization of any land area. Foremost in importance in this respect, stand topography and its constant associate, drainage. The most prominent topographic feature in the southern part of Central Ontario is the interlobate moraine which extends in an east and west direction through the middle of the area. Much of this land is untillable because of the irregularities of the surface; while in addition there are other smaller areas such as rock cuestas, old shore cliffs, recently eroded valleys, and the steep sides of some of the larger drumlins; so that, in all, the proportion of topographically non-arable land amounts to about 8% of the total area of the region. Where the handicap of topographic relief is absent, on the other hand, the hydrographic factor is likely to be most to the fore. The area of flat, swampy and wet land, which is at present restrained from cultivation is only slightly less extensive than that of the rough hilly land.

The presence of solid rock at the surface, or with a very shallow covering of unconsolidated materials, is also a very serious handicap; nearly 12% of the area of the region must be classed as of low agricultural value on account of the lack of depth of its soils. In addition, there is possibly 5% consisting of soils so stony that cultivation is prohibited unless a disproportionate amount of labour is first expended in clearing operations.

It is thus to be seen that, because of the influence of physical factors, somewhat over 30% of the area of the region is to be classed as distinctly submarginal land. On the other hand, nearly half of the area may be rated as first class agricultural land, which, apart from climatic limitations, is as productive as any similar area in the province. The remainder is, in the main, also good land, but of a more limited productive capacity.

Notwithstanding the fact that the physical characteristics are those most definitely limiting the use of land, the chemical characteristics are important; and they are, to considerable extent, linked up with the profile development. The region lies in the zone of the podsolic soils, with mature podsols occurring in some of the more northerly areas, and it is therefore to be expected that leaching is fairly active, and that only moderate amounts of available nutrients will be present. Pedologically speaking, however, they are mostly young soils; hence, they are still greatly influenced by the original constituents of the parent materials.

The outstanding characteristic of the region, from a chemical standpoint, is the relatively large area of alkaline soils, much of which has also free carbonates in the surface layer, especially in cultivated fields. Associated with this is the fact that, even in soils which are somewhat acid, there is plenty of available calcium. In fact, the application of lime in any form is not required for approximately 80% of the area. Magnesium is also usually sufficient. On the other hand, in no case is there more than a moderate amount of available phosphorus, while there

is much land in which there is an acute deficiency. The supplies of available potash are much more variable and range from a condition of acute deficiency to those cases where no addition is necessary. It is, therefore, evident that all fertilizer recommendations should be based upon the natural levels of fertility in the soil as well as the normal requirements of crop plants.

The land type, as here presented, is an attempt to sum up the edaphic factors in such a way as to facilitate the study of land utilization. It is possible that further study, and, especially, comparison with conditions in other parts of the province, will necessitate changes in some of the boundaries. In general, however, the chief types outlined in this scheme will remain a basis for ecological and economic investigations and will point hopefully to the day when similar knowledge will have been made available for the whole province.

CONCLUSION

The southern part of Central Ontario has an interesting and, in some respects, unusual set of soils. Because of the complex geological history of the parent materials, the types are many and varied; hence a complete classification of all the members and an accurate mapping of the same will come only with a detailed soil survey. In the meantime, it is useful to have a general description embodying those physical factors, such as topography, drainage, depth and stoniness, which limit the use of land, as well as those factors of natural fertility which govern soil treatments. Finally by taking into consideration the morphological features of the soil profiles, and by grouping those types which show similarity in the chief characteristics, it is possible to classify thirteen land types which constitute fairly well defined units in the study of agriculatural adaptation. It is, therefore, to be hoped that this account of the soils of south-central Ontario will serve the purposes of geographers and ecologists, and until more detailed soil surveys are made, will constitute a guide to soil treatments, as well as a basis upon which to plan actual tests with fertilizers and different varieties of crop plants.

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METHODS AND RATIONS FOR FATTENING POULTRY[1]

II. EXPERIMENTAL TECHNIQUE AND COMPARATIVE VALUE OF FATTENING RATIONS

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[Received for publication November 12, 1937]

TECHNIQUE

The technique employed in the carrying out of the fattening tests here reported was similar to that previously used and which was set forth in detail in the previous publication of this series (2). Such changes as were made will be noted briefly.

Allotment

The allotment of the cockerels to individual cages of the fattening battery was completely at random in this instance. As an outcome of previous fattening tests it was determined that not less than 40 birds were necessary in each experimental group if small differences (6 to 10%) between treatments were to be demonstrated to be of significance. In employing this relatively large number of birds it was found that the different groups started the test at closely comparable body weights when random allotment was used. This finding was further strengthened by the fact that statistical adjustment of gain for differences in initial weight was negligible when as many as 40 birds were used for each group.

As in previous tests allotment of diets to the individual birds was also at random.

Feeding and Management

Feeding and management was identical to that previously reported. Any differences occurring because of the experimental treatment imposed will be set forth under the experimental detail of each test later in this publication. The tests were of three weeks duration.

Sampling

In the first paper of this series (2) the dressed carcasses of the experimental birds were sampled for determination of fat in such a way that the distribution of fat in the different areas of the carcass could be determined. Since the data obtained clearly indicated that the experimental treatments imposed had no effect upon the deposition of fat in different areas, it was considered to be unnecessary to use distribution of fat as a criterion of the fattening efficiency of a feed or treatment in these tests. As a result the sampling carried out was upon a somewhat different basis.

It was previously shown that degree of fatness at the end of a fattening period was a relatively poor indication of the actual increase in fat during fattening. Preliminary trials were therefore commenced in order to find if possible some measure of the actual increase in fat during the fattening period.

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[2] Poultry Husbandman.

The findings of Hankins and Ellis (3) that thickness of back fat in hogs was a reliable index of the percentage of fat in the carcass was found not to be of practical application to poultry, largely because of the extreme thinness of the fat in that area and of the consequent difficulty in accurate measurement. The percentage of fat in numerous samples of back fat was determined but was found to be a poor indication of the fatness of the carcass as determined by the percentage of abdominal and skin and subcutaneous fats. Difficulty in sampling appeared to be largely responsible for this finding since the great variation in thickness of fat in different areas of the back of poultry precluded the possibility of obtaining an accurately representative fat sample.

A considerable amount of difficulty in finding an area where fat was deposited subcutaneously in sufficiently large and uniform quantities for this purpose was experienced. It was finally found however, that the large feather tract upon the breast parallel to the keel suited the purpose admirably. In three different groups of dressed poultry the percentage of fat in the feather tract sample was found to be highly correlated with the percentage fat of the carcass the actual correlation values ranging from $r = +0.87$ to $r = +0.98$. The following technique was finally adopted.

Prior to commencement of the 24-hour period of starvation which precedes each test each bird was sampled individually. An attendant quickly removed the feathers from the anterior end of the feather tract and injected 5 minims of adrenalin chloride solution (1-1000) into the skin at the base of the feather tract and near the site of operation to prevent excessive bleeding. A local anaesthetic was then applied in the form of ethyl chloride. When freezing had progressed sufficiently the operation was performed. A strip of skin with adhering subcutaneous fat approximately one-half centimetre wide, at right angles to the feather tract and exactly the width thereof, was removed and transferred to a weighed test tube. Since the subcutaneous fat of the feather tract diminishes in thickness from the centre of the tract to the outside edge both ventrally and dorsally and also diminishes in both width and thickness anteriorly it was found to be essential to sample at the same relative distance from the anterior point of the feather tract in each bird in order that the samples taken might be strictly comparable. After removal of the sample the bird was released without suture of the wound. It should be stressed that since skin and subcutaneous fat only are required there exists no necessity for injury to the breast muscle tissue in any way. In only a very few instances did persistent bleeding occur and infections were but rarely encountered and those not severe in nature. Further, no evidence could be found to indicate that the birds had received a set-back through this operation, appetite and fattening apparently being normal throughout.

At the completion of the fattening test the birds were slaughtered and an identical sample from the feather tract of the opposite side of the body was taken to represent the degree of fatness at the end of the fattening test. That the two sides of the same bird are in excellent agreement as to level of fat in skin and subcutaneous tissues was previously reported by the author (2). The difference in percentage fat between the sample taken before and that taken after fattening represents the increase of fat in that area during the fattening period, and in view of the excellent correlations between the

fat content of such samples and that of the whole bird, this difference was considered to be an excellent indication of the increase in fatness brought about by the fattening treatment for the individual concerned. Percentage increase in fat in these papers refers therefore to the increase thus obtained.

Chemical Analyses

The samples of the feather tract taken as above were placed in weighed test tubes and the weight of tube and sample recorded. Concentrated HCl was then added to each just sufficient to cover the sample. After digestion in a water bath until completion the fat was determined by the Mojonnier method. The fat obtained was then expressed as percentage of the original weight of the sample.

Increase in Fat

As was found to be the case with gain, increase in fat varied considerably from bird to bird. Analyses of the data obtained indicated that percentage gain in weight and percentage increase in fat during fattening were related only to a small degree showing an actual correlation of $r = +0.25 \pm 0.076$. It must be presumed, therefore, that a large portion of the actual gain must be in the form of protein (as muscle tissue), water, or minerals (largely bone materials). It is quite apparent therefore that increase in weight during fattening is an indifferent indication of the increase in fatness of the bird. In order therefore, to determine the efficiency of any feed in promoting the fattening or finishing process, as it is sometimes called, both the gain in body weight and the increase in fat must be determined. On correlating the percentage initial fat with the percentage gain in fat it was found that a fairly high negative correlation existed, *viz.* $r = -0.67 \pm 0.044$. As would be expected therefore, the less fat which a bird possesses at the commencement of a fattening period the greater the increase in fat will be, on the average, during that period.

A brief discussion of the practical aspects of increase in fat as opposed to gain in weight may be in order. Fattening for market is generally considered to be necessary for two reasons, namely, to increase the amount of fat upon the bird thus greatly improving its edible qualities and its saleable appearance, and to increase the weight of the bird at the same time. Increasing the fat, besides making the bird more attractive for sale purposes, places the bird in a higher market grade, thus demanding a premium of usually a minimum of two cents per pound for each grade of improvement. Under the present system of Dominion Government grading, therefore, the actual increase in fat brought about by the fattening process returns a special premium to the producer over and above the profit obtainable by reason of the actual increase in weight during fattening. It is important to note that the premium per pound is obtained not only upon the increased weight caused by the fattening treatment but upon each pound of the birds' weight; *i.e.*, if a 6-pound bird, in fattening, improved by one grade and was raised to 7 pounds in weight, besides the profit from the added pound of weight a premium of at least 14 cts. is obtainable as a reward for the increase in quality.

In determining the value of any feed or treatment for fattening purposes, therefore, the necessity for knowing the ability of that feed or treatment to increase fat as well as body weight becomes obvious. As a consequence, increase in fat represents an indispensable criterion of efficiency in experimental fattening tests.

COMPARATIVE VALUE OF FATTENING RATIONS

One series of fattening tests has been carried out to date based upon the experimental technique just considered. The test comprised 4 groups of 40 Barred Rock cockerels each on a different feeding treatment as indicated below. The cockerels were fattened in an individual compartment battery so that individual feed consumption figures would be available. Two feeds daily were given, morning and evening each of 20 minutes duration. The feeds given to each group were as follows:—

Group A—Ground yellow corn plus 5% of feed molasses mixed with skim-milk.

Group B—Ground yellow corn plus 5% of ground oyster shell mixed with skim-milk.

Group C—Ground yellow corn plus 5% of mutton fat mixed with skim-milk.

Group D—Control group—ground yellow corn mixed with skim-milk.

The feeds being contrasted for fattening efficiency have been investigated at various times by different workers. Some disagreement exists as to the efficiency of the feeds used, and the experimental techniques in some instances, particularly in the older experiments, were open to question. Bittenbender and Lippincott (1) reported as a result of their experiments that the addition of 10% of molasses to a fattening ration slightly increased the average gains on a somewhat smaller feed consumption. It did not, however, appear to improve the palatability of the ration. Since molasses represents a product composed largely of sugars, the work of Hartwell and Kirkpatrick (4) is of interest. They found that sugar at the rate of 20 to 100 grams per quart of milk used in mixing the fattening ration did not increase gains or palatability.

Calcium salts of organic acids were found by Solun and Schuster (7) to influence favourably the appetite of animals during the whole fattening period and because of resultant increased feed consumption, the quantity and quality of gain. They concluded that acid base balance is one of the main factors in regulating the appetite of the fowl during fattening.

Lee (5) after summarizing the fattening processes of a large number of fattening establishments came to the conclusions that the addition of 6% of tallow gave less uniform results than the ordinary ration and required the same amount of feed to produce one pound of gain. In Wright's Book of Poultry (8) the practice of adding fat to the ration is set forth in great detail and its efficiency unquestioned. Recently the Ministry of Agriculture and Fisheries of Great Britain (6) have published data in which the addition of 6 or 7% of mutton tallow increased gains in 18 out of 20 groups of birds. These results were obtained by cramming rather than free feeding and for a period of 10 days subsequent to a similar period of trough fattening.

It should be mentioned that ground yellow corn was used as the control ration because of its marked superiority to other grain rations used in previous tests (2).

Reviewing the experimental feeds set forth above, molasses was used as a presumably readily available source of carbohydrates (sugars in this instance) which might well supplement the carbohydrates and fat of the

grain ration with resulting increase in fat. Calcium carbonate was used as a supplement since it was felt that some form of calcium might well increase the consumption of feed and hence improve fattening. Ground oyster shell was the calcium supplement used since it is a cheap and easily obtainable form of calcium carbonate. Fat, and particularly mutton tallow, has been used for many years for fattening purposes and has been considered to be very valuable for fattening. It is claimed particularly to lay down a quality of fat which greatly enhances the appearance of the dressed bird. Mutton tallow was therefore used in order to justify these claims or otherwise in a controlled experiment under fattening conditions similar to those in commercial practice, and fed in a more practical manner than the usual cramming method. The supplements mentioned were all, with the exception of molasses, added to the dry ground corn (the tallow in rendered form) and the skim-milk added so that the same amount of milk was used in each ration. In order that the consistency of the mixed mash might be similar for all pens a small amount of water was added to the skim-milk where necessary to bring each to the proper consistency. It was found to be more advantageous to add the correct amount of molasses to the skim-milk thoroughly mixing it in before adding the ground corn. The mutton tallow when melted was quickly mixed before cooling with a small amount of corn meal and this in turn mixed with a larger quantity to assure thorough mixing. Where lumping of the fat occurred the mixed corn and fat was forced through a screen so that a thorough mixing of the fat was possible.

Results

TABLE 1.

Group	No. of birds	Actual gain	Adjusted gain	Consumption dry matter	Increase in fat	Adjusted increase in fat
		gms.	gms.	gms.	%	%
A. Molasses	37	439.1±28.2	395.3±13.4	2705±62.0	17.4±1.24	17.3±0.85
B. Calcium carbonate	40	472.3±27.1	410.3±12.9	2839±59.5	18.3±1.18	18.0±0.80
C. Fat	39	516.7±27.4	567.7±13.1	2662±60.2	20.0±1.18	21.4±0.83
D. Control	39	425.0±29.4	416.5±13.1	2581±60.2	15.4±1.19	18.1±0.82

Table 1 indicates the results obtained. It will be noted that the data from five individuals were not used in calculating the results. Of these, one individual died during the test, one injured its beak so that it was unable to feed, one individual was definitely sick and consumed no feed, while two others consumed so little feed that their maintenance requirements could not be met so that fattening was out of the question. Individuals whose gain is apparently abnormal, either on the high or low side, and which might logically be eliminated on a statistical basis were not eliminated in these tests unless their feed consumption was so low as to be submaintenance and there was therefore no possibility of their gain or loss being a reflection of the value of the feed which they received for fattening purposes.

As previously reported in this series, actual gain was adjusted for the effect of varying feed consumption so as to place the gain upon the basis of expectancy with equal feed consumption. In these tests the

percentage increase in fat was adjusted for the effect of initial percentage fat on increase in fat. Not only does the application of this statistical treatment increase the value of the comparison because of holding the variables feed consumption and initial weight constant, but the standard deviations of gain and of increase in fat were reduced from 169 to 81 and from 6.76 to 4.97 respectively. Actually therefore the sensitivity of the test was increased by approximately 47% by the adjustment of gains for effect of feed consumption on gains and that of increase in fat for effect of initial fat by 27%.

Gain in Weight

Considering the results obtained in assaying the value of the feeding treatments given, it will be noted that group C receiving mutton fat was significantly greater in actual gain than all other groups with the exception of that receiving calcium carbonate. When the gain is adjusted for the effect of varying levels of feed consumption the gain of the group receiving fat is again outstanding being significantly greater than that of all other groups. This efficiency of use of feed is reflected by the fact that the percentage of fat in the faeces of the fat-fed pen was not significantly greater than that of the control. All other differences are too small to be of significance. From the standpoint of gain in weight, therefore, the addition of 5% of mutton tallow to a fattening mixture of ground corn and skimmilk is outstanding, the actual increased gain on an equal consumption basis through this addition being 27%.

Feed Consumption

In the matter of feed consumption, as indicated by the data, the group receiving calcium carbonate was outstanding with a 10% and significantly greater feed consumption than the control group. Since no other group had a significantly higher feed consumption than the control group the supplement calcium carbonate obviously caused a very definite increase in feed consumption.

Increase in Fat

Considering increase in fat which, as noted, is the best criterion of the ability of a feed to fatten, it is apparent that the addition of mutton fat to the ration has given outstanding results. In actual increase, there is a difference of a 23% greater increase in fat where 5% of mutton fat was fed. When the actual increase is adjusted for the effect of varying degrees of fatness at the commencement of the fattening period thus furnishing a fairer basis for comparison, the group receiving fat is still outstanding (15% difference), the other three groups being approximately equal. It may be concluded therefore that the addition of 5% of mutton fat to the cereal fattening ration used definitely increased the level of the fat deposited in the body. The use of molasses apparently did not affect either gains or increase in fat.

Quality of the Dressed Bird

In order to measure the actual visual quality of the birds which received the various feeds all birds were graded according to the Official Canadian Government Standards for Dressed Poultry by an officer of the Poultry Services of the Live Stock Branch. Such grading is based largely upon

two qualities, namely, the degree of fatness of the bird and the body conformation. Since in groups of similarly selected and treated stock whose numbers are as large as those herein (40 birds per group) each lot should be reasonably similar at the start of the test, grade differences of any magnitude may without doubt be safely attributed to the experimental treatment given. As definite evidence in support of this contention the fact may be cited that no differences could be demonstrated in the breast angle, the most important measure of conformation, between groups. The actual grading of the birds was as follows:—

Grade	Molasses	Calcium carbonate	Mutton fat	Corn
	%	%	%	%
A	47 3	55 0	74 3	57 5
B	52 7	45 0	25 7	42 5

It is quite apparent from the above data that the greater increase in fat of the group receiving mutton fat is reflected in the actual grade which the birds attained, a difference of 16 8% more grade A birds being indicated. It would also appear that the difference in the percentage of grade A birds between the control (corn) and molasses pens (10 2%) may be of some significance. In spite of the fact that these groups were of equal fatness at the end of the test (55 52% and 56.65% respectively) the molasses fed birds were degraded presumably because of a less attractive finished appearance.

SUMMARY

Technique

The matter of the most desirable technique in fattening experiments has been further investigated. The data reported herein have added to the available information to some degree. A contention previously made has been further strengthened in that under favourable conditions of fattening environment and using statistical technique which reduces variability to a very great degree, at least 40 individual birds are required in each group in order to be able to demonstrate small differences of practical value (6 to 10%) in the effect of feeds or treatments to be significant. Further, with the variability experienced in fattening tests at this institution during the past three years, unless adjustment is made statistically for the effect of variation in feed consumption on weight gains, differences of less than 10 to 15% cannot be demonstrated.

Since it was considered to be necessary to determine the ability of a feed to increase the amount of fat deposited during fattening as well as its ability to influence the degree of gain in weight, the possibility of sampling live birds at the commencement of a fattening test and their dressed carcass at the end in order to determine the increase in fat was investigated, a satisfactory technique, the details of which have been set forth herein, resulting. By the application of this technique it was found to be possible to estimate the increase in fat with a reasonable degree of accuracy.

Comparative Value of Fattening Rations

The above techniques were applied in fattening tests to determine the value of the following rations: A—ground yellow corn + 5% molasses; B—ground yellow corn + 5% of calcium carbonate; C—ground yellow

corn + 5% mutton fat; D—ground yellow corn (control). All rations were mixed with skim-milk.

It was found that the addition of 5% of mutton fat increased the gains made by 18%. On the basis of equal feed consumption it increased the gains by 27% indicating that the efficiency of the feed as a producer of gain was considerably greater when fat was added. In addition the actual amount of fat deposited upon the body during the experiment was increased by 23% by this supplement. It happened, however, that the birds of this group were, by chance, less fat than those of the control group at the commencement of the test. Since leaner birds put on fat in greater quantities regardless of the ration fed, when allowance was made statistically for this unfair chance advantage, the actual greater increase in fat for the fat fed pen was reduced to 15%, still a substantial increase in fat producing ability. Finally, the increase in fat thus made was largely responsible for superior grading of the birds according to Canadian Government Standards, there being 17% more A grade birds in the group fed mutton fat.

The addition of 5% of calcium carbonate to the ration increased the gain made by 10%, a non-significant increase. As this increase was made upon a much greater feed consumption, the efficiency of production of gain was therefore not increased. Feed consumption, however, was significantly increased by 10%. Since the body weight of all groups was almost identical at the commencement of the test no greater requirement for maintenance existed for this group and consequently it may be safely considered that this addition definitely increased the palatability of the ration.

The use of 5% molasses in the fattening ration had no significant effect upon gains, feed consumption or increase in fat, detrimental or otherwise, although the actual grading of the dressed birds of this group was definitely inferior to that of the control group.

CONCLUSIONS

Technique

1. The most valuable criteria of the quality of a feed or treatment to fatten poultry, namely, gain in body weight and increase in fat, have consistently been found to be so variable that the following measures of technique are considered to be necessary:—

(a) The use of a relatively large number of individuals in each experimental group (at least 40 under the conditions of these tests).

(b) The reduction of variability and the adjustment of means for the effect of correlated variables such as feed consumption, initial body weight, initial level of fat, etc. which if not adjusted for, seriously affect the validity of the comparisons made.

2. An efficient technique for estimation of the increase in body fat during fattening tests has been determined and may be used to very satisfactorily assay this criterion of fattening ability.

Fattening Trials

1. The addition of 5% mutton fat to a fattening ration increased the gain by 18%, the efficiency of use of feed by 27%, the increase in percentage of fat by 15%, and the percentage of A grade birds by 17%.

2. The addition of 5% calcium carbonate (ground oyster shell) to a fattening ration improved palatability as indicated by an increase in feed consumption of 10%.

3. The addition of 5% of molasses to a fattening ration did not affect gain in weight, feed consumption or increase in fat. Fewer A grade birds by 10% were produced by this addition, however.

ACKNOWLEDGMENT

The co-operation of Dr. A. R. G. Emslie of the Division of Chemistry of the Central Experimental Farm through the carrying out of chemical analyses is gratefully acknowledged.

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THE HIGH COMPRESSION ENGINE FOR THE FARM TRACTOR

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In 1931, when attending the A.S.A.E. Convention in Iowa, the author met Mr. G. Grieger of the Ethyl Gasoline Corporation, who outlined the work then being done experimentally with the high compression engine for the farm tractor. At that time the high compression engine was being placed in the automobile with remarkable results as to economy and increased horse power. The research work on antiknock fuels was well in hand, and distribution of the fuel throughout North America was sufficiently complete so that it could be had practically in any locality.

The position of the farmer in 1931 and since that time has not been good. He has been trying to use cheaper fuels in an attempt to reduce cost per acre for the power used in producing crops. Consequently, the tractor manufacturer was not ready to change from a general type of all-fuel engine to a special-fuel engine for tractors. Since 1931, however, the automobile manufacturer has gradually increased the compression ratio in the automobile engine. Table 1 shows the increase in compression ratio and H.P. per cubic inch of displacement:

TABLE 1

—	Ave. comp. ratio	H. P. per cu. in. displacement
1931	5.23	0.344
1932	5.29	.353
1933	5 57	.376
1934	5.72	.388
1935	5.98	.398
1936	6.30	.410
1937	6.50	.420

The power of the automobile engine was increased 92% from 1925 to 1936 while the size of the engine was increased only 11%. The power increase has been due to higher speed and increase in compression.

The designer of the tractor has been watching the results of the development in the automobile and truck engine with considerable interest. He has seen the motoring public accept the high compression engine and the special fuel which must be used for performance, without criticism. The power and economy of the high compression engine in the automobile and truck were both important factors in producing the engine performance which was demanded by the motorist.

Economy is the main demand of the farmer, generally speaking. He does not need the extra power. Consequently, the tractor designer has hesitated somewhat in changing over to the high compression tractor engine until the demand from the farmer is more urgent.

There is no question as to the fact that the present tractor engine which uses gasoline, kerosene or distillate equally well cannot be most efficient on any one fuel but the lowest grade. Table 2 shows the efficiency and power of engines tested on various fuels.

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[2] Paper read before the Agricultural Engineering Group of the C.S.T.A., at the University of Saskatchewan, June 1937.

TABLE 2

Test No.	Fuel	H.P.	Economy H.P.Hr.	Temperature, ° F.			Remarks
				Rad.	Intake	Exhaust	
Hart-Parr 18-28							
1	Plain	24.9	0.75	159	149	953	No ping
2	Green	24.8	0.75	158	140	950	No ping
3	Red	24.7	0.75	161	144	948	No ping
4	Plain tractor gas	21.5	0.74	144	140	980	No ping
5	Plain tractor gas	21.7	0.71	171	200	1020	Hot manifold
6	Kerosene	24.9	0.763	176	215	1000	No ping
7	No. 1 distillate	26.0	0.771	198	220	1020	No ping
8	No. 2 distillate	25.16	0.78	191	210	1025	No ping
9	No. 3 distillate	25.9	0.78	194	215	1030	No ping
McCormick-Deering 22-36 Standard Pistons							
10	Plain	31.9	0.73	170	156	1210	No ping
11	Green	32.6	0.74	174	142	1180	No ping
12	Red	31.3	0.74	173	150	1175	No ping
McCormick-Deering 22-36 8000 Altitude Pistons							
13	Plain	—	—	—	—	—	Violent pinging
14	Green	32.4	0.62	162	133	1005	
15	Green	39.7	—	—	115	—	Pinging starts
16	Green	41 1	—	—	115	—	Max.
17	Red	38.1	0.576	177	135	1040	No ping
18	Red	42.1	—	—	110	—	Ping starts
19	Red	44.0	—	—	110	—	Max.
Hart-Parr "70" High Compression							
20	Green	17.9	0.66	—	—	—	No ping

The engine of the farm tractor designed to burn kerosene or distillate does not burn gasoline more efficiently. It will usually develop more power from gasoline. The tractors which we have tested have shown greater maximum power from gasoline than from the heavier fuels: *e.g.*, Case L, 43.5 H.P. as compared to 38.2 on distillate; Hart-Parr 27.8 as compared to 26.8 on distillate. The tractor designed to burn distillate which is operated by a man who knows how to condition the tractor for distillate burning, operates for less per acre than the same tractor using gasoline, the reason being that the field efficiency is practically the same and the weight per gallon of fuel is less as well as the cost being less (gasoline 7.4 lbs. kerosene 8.02 lbs. and distillate 8.2 lbs. per gallon).

The question of wear when using distillate is dependent on the individual engine and the routine care given by the operator. There are many 10- and 12-year old tractors which have operated on all fuels very satisfactorily as far as wear and upkeep are concerned, while there are others which seem to have worn out for some unknown reason. The fuel has usually, in such cases, borne the blame. Our experience would tend to indicate that when the engine is operated intelligently and is kept in good condition no extra wear can be charged to the fuel used.

The cost of lubricating oil is usually higher. The common practice of changing the oil every 60 hours as compared to 100-120 hours and dis-

carding the oil brings about an increase in cost. The quality of the oil used and the cost of the oil is the same for both fuels.

We have found that there are many farmers who have never used either kerosene or distillate satisfactorily. These men have consistently used gasoline, and many have used green gasoline thinking that the green gasoline would give better results than the plain. This percentage would be 30% in some areas and as high as 50% or 60% in others where crops have been more consistent. For such operators the high compression engine on the tractor certainly will make a saving. The Nebraska test on the Twin City M.T.A. and K.T.A. is a good example. Using the same engine and tractor except for the compression, the tractor developed a H.P.Hr. on 0.697 lbs. of fuel on distillate and 0.545 lbs. on gasoline with the high compression. The saving was 21.8%. It also operated on ¾ load on 0.740 lbs. per H.P.Hr. as compared to 0.595 lbs. per H.P.Hr. on gasoline with a saving of 19.6%. The saving on the drawbar is practically the same, 0.988 lbs. on distillate and 0.795 lbs. on gasoline, being a saving of 19.3%.

The cost of gasoline varies throughout the province of Saskatchewan according to the freight charges. The Saskatoon prices to the farmer delivered in barrel lots are as follows:

Red Ethyl	27.3¢ per gallon
Green Ethyl	25.3¢ per gallon
Plain first grade	25.3¢ per gallon
Plain third grade	20.8¢ per gallon
Distillate	19.3¢ per gallon
Diesel Fuel	16.6¢ per gallon

Basing the fuel price study on the price of distillate the cost of plain third grade gasoline is 7.75% higher, and first grade or green gasolines are 31% higher, which means that the operator who was successfully using distillate loses the saving made by the increase in engine efficiency made by the increase in cost of the fuel. However, the man using green or first grade plain gasoline in an engine with standard compression can make the full saving of 19.3% in the case of the Twin City by using the high compression engine. The spread in price between the tractor gasoline and third grade gasoline is high enough to just about equal the increase in efficiency of 21.5%.

There are a number of tractors shown in the Nebraska test lists which are high compression. Hart-Parr "70", Test No. 256 showing 0.564 lbs. of fuel on the belt and 0.809 lbs. on the drawbar. The Co-Op No. 3 tractor, test No. 274, with 0.561 lbs. on the belt and with 0.649 lbs. on the drawbar. The drawbar tests, however, are made on rubber also Co-Op No. 2, 0.580 lbs. on the best and 0.654 on the drawbar with rubber.

There are a number of tractors with standard equipment which may be changed over to high compression if desired by putting in high altitude pistons and liners. The 8000 altitude pistons were tested out in comparison with standard equipment with quite satisfactory results as indicated in Tests 10 to 19 inclusive. The high compression engine on the farm tractor makes a direct fuel saving for the tractor operator who is at present using gasoline which is ample to warrant the change to high altitude piston equipment or to the high compression tractor.

AN ANNUAL SWEET CLOVER (*M. ALBA*) OF THE DWARF BRANCHING TYPE[1]

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[Received for publication November 12, 1937]

A sweet clover plant, which blossomed profusely and matured an abundance of seed during the first year's growth, appeared in a single plant progeny of Alpha 3, a dwarf branching biennial form of *M. alba*, in the field nursery at Saskatoon in 1932. All of the remaining plants in this progeny were of the dwarf branching type and none of them produced any flowers during the same year that they were sown. Not infrequently biennial plants of common white blossom sweet clover produce some flowers during the year of seeding, but blossoming on such plants usually begins late in the season and only a few seeds are matured; hence, since this plant produced an abundance of mature seed, the same year that it was sown, it appeared to be annual in habit of growth. A close examination of the plant showed that no crown or resting buds were formed such as are normally produced by the biennial sweet clovers and the plant failed to make any growth the following spring.

All of the seeds produced on this annual plant in the field resulted from open pollination. A number of cuttings were made from the plant, however, and these were rooted and grown to maturity in the greenhouse during the winter of 1932–33. Self-fertilized seeds obtained from the cuttings were sown in 1933 and approximately 100 plants were grown in the field nursery. All of these plants behaved as true annuals, blossoming and maturing an abundance of seed during the year of seeding. All of the plants were also of the dwarf branching type.

An isolated increase plot was sown in the spring of 1934 and the plants produced seed under field conditions. Since that time a number of seedings have been made, both for seed increase and for bee pasture purposes.

Comparison with the Common Biennial White Blossom Type

Botanically, this plant differs from the common biennial white blossom type of *M. alba* in several characteristics. It is distinctly annual in habit of growth and makes rapid growth early in the season. It begins to flower almost as early as many of the biennial varieties and earlier than some of them. It matures an abundance of seed, does not produce crown or resting buds, and dies during the season of seeding. The roots are somewhat smaller and less fleshy than those of the biennial forms. Flowering begins from the first to the tenth of July, at Saskatoon, while the plants are from 6 to 8 inches tall. Flowers are produced in increasing abundance as growth continues, usually reaching a maximum in late August and then decreasing until late September when the plant reaches maturity; hence the flowering period covers a period of from 10 to 12 weeks, as compared to a flowering period of from 4 to 6 weeks, which is usual for the biennial types under similar conditions.

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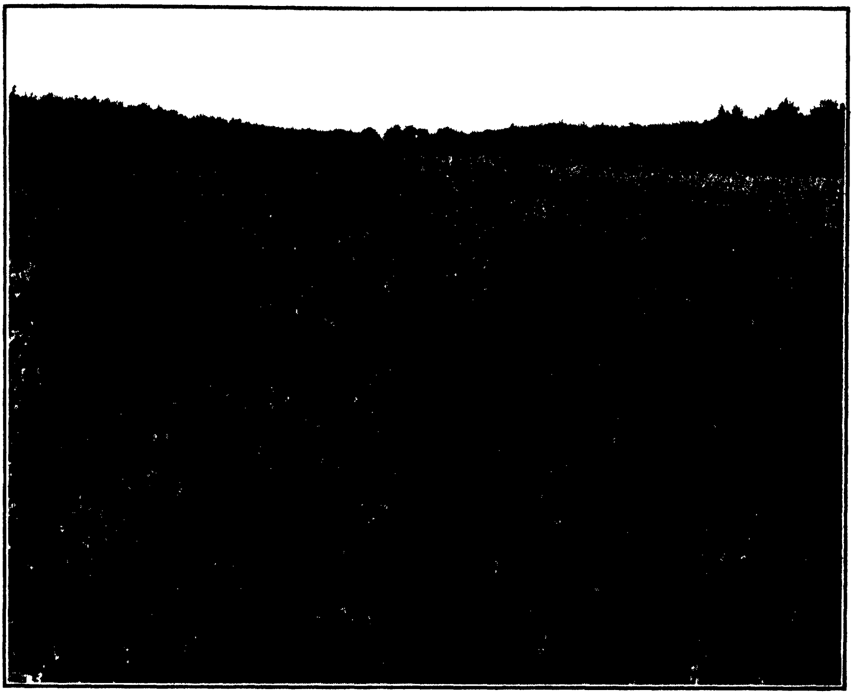

FIGURE 1. A seed increase plot of annual dwarf branching white blossom sweet clover.

FIGURE 2. A single plant of annual dwarf branching, white blossom sweet clover, *M. alba*, showing the much branched, fine stemmed leafy type of growth.

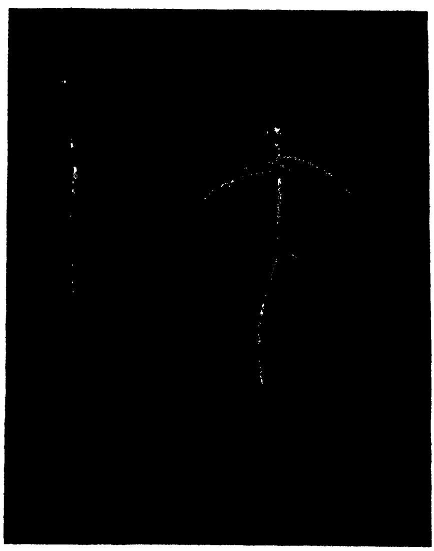

FIGURE 3. Roots of white blossom sweet clover, showing crown branching and absence of crown buds on the annual dwarf branching type (a) and the single stem from the first year's growth and well developed crown buds on the biennial type (b).

The leaves, flowers, pods and seeds are indistinguishable from those of the common biennial forms of *M. alba*. The crown of the plant branches to form from 7 to 18 stems and these in turn branch and rebranch at short intervals near the base to produce a very fine-stemmed bunch-type plant. Unlike the biennial types, the plant grows over a fairly long period and maintains a high percentage of leaf long after seeds have matured from the earlier flowers. This leafy condition continues often until mid-September, when the whole plant usually shows signs of maturing.

Comparison with the Hubam Variety

The data given in Table 1 were obtained from plants of the dwarf branching annual and Hubam, grown under similar conditions at Saskatoon during the past three years.

TABLE 1

——	Dwarf branching annual	Hubam
Date of beginning to flower	July 2 to July 10	July 28 to Aug. 6
Length of flowering period	10 to 12 weeks	5 to 7 weeks
Production of mature seed	Abundance	Very little
Height	2′ 8″ to 3′ 11″	2′ 8″ to 4′ 3″
Leafiness	Heavily leaved	Sparsely leaved
No. of stems per plant (arising from crown)	10 to 18	1

In habit of growth both are annual, but the two plants show striking differences in several important characteristics. The much branched crown and numerous fine leafy stems of the dwarf branching annual contrast strongly with the sparsely leaved, single branched stem of the Hubam variety. The earlier flowering and longer flowering period of the dwarf branching annual makes it of greater value for bee pasture. Due to the earlier maturity, this plant produces an abundance of seed, whereas little or sometimes no mature seed has been obtained from the Hubam variety under similar conditions at Saskatoon.

Possible Uses for the Dwarf Branching Annual

Sufficient data are not yet available to permit an accurate estimate of the agricultural value of this plant. The characteristics of the plant, however, indicate that it may be of value for pasture purposes, particularly for late summer pasture, since it retains its leaves until early fall. The plant appears to offer greatest possibilities for bee pasture purposes. The long flowering period, which continues for several weeks after the biennial sweet clovers have completed flowering, should serve to provide bee pasturage at a season when there is normally a scarcity of nectar bearing plants. Beekeepers who have grown the annual dwarf branching plant state that the bees work the flowers heavily during the entire blossoming period.

As an orchard crop and as a green manure crop, the annual dwarf branching sweet clover may be of value. Being an annual crop, it may be safely plowed in the fall of the year of seeding, whereas the biennial sweet clovers often renew growth the following spring, when plowed down in the fall of the first year.

Inheritance of the Annual Habit

The annual dwarf branching strain was crossed with the common biennial white flowered sweet clover and 21 seeds were obtained. Nineteen of these produced annual plants similar to the male parent. Two produced biennial plants like the female parent and apparently arose from self-pollination. Self-fertilized seeds were obtained from each of the hybrid plants and 19 F_2 progenies, totalling 1272 plants, were grown. Each F_2 progeny was examined and classified on the basis of annual or biennial type. In the classification of this material, it was noted that certain plants which blossomed in the first year were much later in flowering than others; hence classification was based upon the presence or absence of crown or resting buds, as well as upon flowering habit. The data obtained are shown in Table 2.

TABLE 2.—GOODNESS-OF-FIT TEST, BY MEANS OF X^2 DISTRIBUTION, APPLIED TO 19 F_2 FAMILIES WHICH SEGREGATED FOR ANNUAL AND BIENNIAL HABIT OF GROWTH

Plant type	O	C	O − C	$(O - C)^2$	$\frac{(O-C)^2}{C}$
A	118	115.50	2.50	6.2500	0.054112
B	36	38.50	2.50	6.2500	0.162337
A	99	98.25	0.75	0.5625	0.005725
B	32	32.75	0.75	0.5625	0.017175
A	102	105.75	3.75	14.0625	0.132987
B	39	35.25	3.75	14.0625	0.398936
A	13	15.00	2.00	4.0000	0.266667
B	7	5.00	2.00	4.0000	0.800000
A	37	35.50	2.50	6.2500	0.181159
B	9	11.50	2.50	6.2500	0.543478
A	13	16.50	3.50	12.2500	0.742424
B	9	5.50	3.50	12.2500	2.222727
A	15	15.00	0.00	0.0000	0.000000
B	5	5.00	0.00	0.0000	0.000000
A	48	47.25	0.75	0.5625	0.011905
B	15	15.75	0.75	0.5625	0.035714
A	18	15.00	3.00	9.0000	0.600000
B	2	5.00	3.00	9.0000	1.800000
A	33	33.75	0.75	0.5625	0.016667
B	12	11.25	0.75	0.5625	0.050000
A	12	14.25	2.25	5.0625	0.355263
B	7	4.75	2.25	5.0625	1.065789
A	45	48.00	3.00	9.0000	0.187500
B	19	16.00	3.00	9.0000	0.562500
A	51	53.25	2.25	5.0625	0.095070
B	20	17.75	2.25	5.0625	0.285211
A	42	43.50	1.50	2.2500	0.051724
B	16	14.50	1.50	2.2500	0.155172
A	123	119.25	3.75	14.0625	0.117924
B	36	39.75	3.75	14.0625	0.353773
A	64	63.75	0.25	0.0625	0.000980
B	21	21.25	0.25	0.0625	0.002941
A	18	16.50	1.50	2.2500	0.163364
B	4	5.50	1.50	2.2500	0.409090
A	65	66.75	1.75	3.0625	0.045880
B	24	22.25	1.75	3.0625	0.137640
A	33	32.25	0.75	0.5625	0.071442
B	10	10.75	0.75	0.5625	0.052325

$N = 19$ $X^2 = 12.074592$ $P =$ Between 0.8 and 0.9

These data were tested for goodness of fit on the basis of a 3 : 1 segregation, both individually and collectively, by means of the X^2 distribution; X^2 for the 0.05 point and one degree of freedom is 3.841, which is greater than the X^2 value obtained for any one of the F_2 progenies. The total X^2 for the 19 progenies is 12.0746. The corresponding P value for $N = 19$ is between 0.8 and 0.9, which may be interpreted to mean that deviations as great or greater than the observed could be expected more than 80 or 90 times in 100 trials on the basis of random sampling. This is a very close fit and indicates that the annual habit is inherited as a simple dominant to the biennial habit in crosses between the annual dwarf branching type and the common biennial type of *M. alba*. This corresponds with the results obtained by Smith (6) and Clarke (2) in studies conducted on the inheritance of the annual character in *M. alba*.

Origin of the Dwarf Branching Annual

This plant occurred suddenly in a dwarf branching biennial line which had been inbred for several generations. Only one variety of annual white blossom sweet clover, Hubam, had been included in our field trials prior to the appearance of this plant. Since the Hubam variety is of the common type of growth, the F_1 plant derived from a cross between it and the dwarf branching biennial would be expected to exhibit the common type of growth also, as shown by Kirk (4, 5), Elders (3), Clarke (1) and Stevenson (7). Since this new annual selection was of the dwarf branching type and since succeeding generations failed to show any tendency to segregate for type of growth, it is evident that the dwarf branching annual did not arise from a natural cross.

Reciprocal crosses were made between the Hubam variety and the annual dwarf branching selection. All of the F_1 plants were annual in habit of growth and no segregation for annual and biennial habit occurred in the F_2 progenies. These results indicate that both of the parents used in this cross possess the same dominant factor for the annual habit. From these data it is evident also that the two dominant mutations must have occurred independently.

SUMMARY

1. An annual plant of the dwarf branching type appeared spontaneously in a line of biennial dwarf branching sweet clover, *M. alba*.

2. The agricultural possibilities of this production have not been fully investigated but it is believed that it may be of value as a bee pasture plant.

3. In crosses with the common biennial, white blossom sweet clover, the annual habit was shown to behave as a simple dominant to the biennial. F_2 progenies from these crosses gave 3 : 1 segregations for annual and biennial habit of growth.

4. Evidence is submitted to show that this new annual arose as a mutation.

5. Results from reciprocal crosses between the dwarf branching annual and Hubam indicate that both plants possess the same dominant factor for the annual habit.

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BOOK REVIEW

SMITH, KENNETH—A Text Book of Plant Virus Diseases. J. & A. Churchill Ltd., 104 Gloucester Place, Portland Square, London.

The *Textbook of Plant Virus Diseases* by Dr. Kenneth Smith of Cambridge University, England, (J. & A. Churchill Ltd., 1937) is a timely addition to the literature of plant pathology. Owing to the multiplicity of papers that have been published during recent years describing plant viruses and virus diseases, plant pathologists have found it difficult to decide whether viruses discovered locally have not been studied and described already elsewhere. Smith's textbook brings together all the principal descriptions of plant viruses and virus diseases in a systematic manner based upon the virus nomenclature scheme suggested by Dr. James Johnson of Wisconsin at the last International Botanical Conference in Amsterdam. The viruses are given the generic name of a host and arabic numerals to indicate distinct types and letters in addition where distinct strains of a major type are described. This method preserves the continuity of current practice, *e.g.*, "Nicotiana virus 1A" and "1B" represent two strains of "Johnson's Tobacco virus 1." The generic name chosen represents the host upon which the effect of the viruses was first described or upon which subsequent descriptions of virus symptoms were more adequate. Owing to the support already given this scheme of nomenclature by both American and European workers, the publication of this textbook will tend to establish order in the chaotic condition of the virus literature with respect to nomenclature.

Very few descriptions of plant viruses have escaped review in chapters I to VII inclusive. Dr. Smith is fully aware that he has given arabic numbers to signify distinctiveness to viruses that later may be proven to be closely related strains of the same basic type. Already, in spite of the limitations of serological methods in virus classification, relationships have been established by this method between plant viruses formerly considered distinct.

The description of the insects involved in virus transmission and their life histories in chapter VIII serves to focus attention upon insects as vectors of virus diseases, a field that is a challenge to scientists. In spite of the highly infectious character of "Solanum Virus 1" as judged by plant juice transfers and the fact that the majority of European and practically all American varieties of potatoes are infected, no one has secured satisfactory evidence that this virus is transmitted from plant to plant by thrips or other insects.

The final chapter deals with a large group of plant species that exhibit chlorotic or other symptoms that suggest virus infection but wherein the infective character of the disease has not been proven.

A three-column appendix of 37 pages is included to assist students in the diagnosis of virus diseases. All common hosts are listed alphabetically opposite brief descriptions of the diseases to which they are susceptible and the names of the viruses involved.

—W. NEWTON.

SCIENTIFIC AGRICULTURE
Vol. XVIII JANUARY, 1938 No. 5

MINERALS IN POULTRY NUTRITION[1]

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[Received for publication October 15, 1937]

INTRODUCTION

The mineral, inorganic, or ash content of a feed or a bird is represented by the material remaining after incineration of the substance. The last two names are somewhat misleading, since only a part of these minerals is present in the ration or in the bird's body as inorganic elements; the remainder is present in organic combination. For example, sulphur is a constituent of some proteins, and phosphorus is present not only in inorganic form but also in organic combination as nucleoproteins, phosphoproteins, phospholipids and phytates.

Since the greater portion of the mineral content of the bird is contained in the skeleton, the mineral requirements of birds, particularly those of young growing chicks, are often considered on the basis of bone formation only, the fact that minerals have other functions in the living organisms often being obscured. As calcium, phosphorus and, to a less degree, magnesium, play important rôles in this connection, the influence of these minerals on bone formation has been extensively studied. However, they too have other important functions, and interrelationships.

The special functions of some of these minerals will be discussed later. The general functions of mineral elements are as follows:—

1. Minerals maintain the necessary osmotic pressure, surface tension and so forth in the various fluids of the body and so aid in absorption, excretion and secretion.
2. Minerals are concerned in the regulation of the hydrogen ion concentration of the blood and tissues. For example, the acidity of the gastric juice of the proventriculus, which is necessary for the activity of the proteolytic enzyme pepsin, is due to hydrochloric acid derived chiefly from sodium chloride in the blood. The normal pH of blood is partially maintained by the carbonates and phosphates of sodium.
3. The irritability or ability to respond to stimuli of muscle and nerve is dependent upon and influenced by the presence of certain inorganic substances. Calcium is necessary for the transfer of nervous impulses. In this connection there is an interrelationship and balance between sodium, potassium, calcium and magnesium. By upsetting this balance (for instance, by injection of mag-

[1] A resumé of this paper was read at the annual meeting of the Eastern Canada Society of Animal Production, Ottawa, June 16 1937

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nesium sulphate) coma, anaesthesia and paralysis can be induced. The symptoms are rapidly alleviated by the injection of calcium chloride. On the other hand, deficient amounts of calcium in the blood (hypocalcaemia) lead to hyperexcitability and tetany. The rhythmicity of the heart beat is also dependent upon a proper balance between mineral elements. If a beating heart is perfused with a solution, of the proper concentration, of sodium chloride, it soon stops beating. If calcium is added to the solution, the heart resumes beating but it fails to relax properly and finally stops in a state of contraction. Subsequent addition of potassium results in normal beating. But a proper proportion between calcium and potassium is necessary, excess potassium resulting in failure of the heart to contract properly. The chick embryo heart has been utilized by Murray (284, 285) in studying this problem.

4. Minerals are integral parts of living protoplasm. As has been pointed out, phosphorus is an essential mineral in all cell nuclei (nucleoprotein) and in brain and nerve tissue (phospholipins).
5. Minerals constitute the greater part of bones, giving rigidity to the skeleton.

These examples will suffice to demonstrate that minerals are extremely important to the physiological activities of any living organism, in addition to furnishing the framework of that organism.

The question of the "availability" of minerals is important, but the phrases "availability of minerals in a ration" or "percentage absorption of minerals" mean very little since so many factors enter into the processes of absorption and utilization. The "availability" of a mineral is partially dependent upon its ease of absorption which includes solubility. But absorption and assimilation are conditioned by other factors than the "form" in which the mineral is supplied in the ration. Vitamin D increases calcium and phosphorus retention due to either increased absorption from the alimentary tract or lessened excretion from the body or both. Moreover, there is ample evidence that the absorption of an extra amount of potassium involves a greater requirement for sodium. Digestibility trials, even when the technical difficulties attendant upon such experiments with poultry are overcome, give no measure of the utilization of the mineral constituents of a diet, for a mineral may be absorbed from one part of the gut and excreted lower down after fulfilling any function for which it is required while in the bird's body. Iron, if in a soluble form, is absorbed from the small intestine and is excreted into the large intestine. Hence, according to a digestibility trial, iron compounds are not digestible. The difference between the chemical analysis of the ration and that of the combined excreta (faeces and urine) will show the "retention" of any mineral at that particular time and under the particular physiological status of the bird at that time. Previous to the onset of egg production, for instance, the percentage retention of calcium may rise from 20% to 70%.

The minerals taken into a bird's body are constantly being excreted by the kidneys (urine), and intestinal wall (faeces). An excess of a mineral, if within a reasonable range, is rapidly excreted. If a deficiency exists,

the body conserves its supply and lowers its normal excretion. Thus, if common salt is given in somewhat excess amounts, the chlorides in the urine increase. If no salt is fed the amount in the urine rapidly decreases. It will be seen that the kidneys are able to safeguard the body against an imbalance of minerals by this regulatory mechanism but, as will be shown later, if excessive amounts of certain minerals are continuously fed, the safety mechanisms break down, the bird is no longer able to maintain the normal composition of the body fluids and tissues, and injury or death ensues. In fact, the writer is of the opinion that under modern feeding conditions, poultry are more liable to suffer from an excess rather than a deficiency of minerals. However, it should be evident that the percentage retention of any mineral will depend also upon the amount which is fed as well as the previous nutritive regime of the bird to which it is fed. In other words, the availability of a mineral constituent of a ration will vary according to circumstances. For practical purposes, although there is little or no evidence available, it probably is safe to assume that one-third to one-half of the mineral content of a ration is available.

Three very excellent reviews of minerals in poultry nutrition have been prepared by Emslie (102), Cruickshank (82) and Halnan (129). The author has drawn heavily on these publications in preparing this present review. Mitchell and McClure (280) have prepared an outstanding monograph on mineral nutrition. The mineral requirements of poultry have also been discussed by Jull (195), Kaupp (201a), Kennard and Bethke (205a), Halnan (128a), Prentice (321a) and Muller-Lenhartz and von Wendt (282a).

Acid-base balance as influenced by feeding has been investigated by Burchardt (51a), Kaupp and Ivey (201b), Solun and Schuster (356a), Schmidt (339) and Solun and Troitskaya (356b).

1. MINERAL CONTENT OF POULTRY AND EGGS

An adequate mineral supply is necessary for poultry during most of their life span. Their growth is rapid and hence the requirements, particularly of calcium and phosphorus for bone formation, are high. At maturity, egg production necessitates a considerable quantity for the formation of eggs, particularly calcium for shell formation. Halnan (129) gives the analysis in Table 1 for an average egg (including shell) weighing 2 ounces. Mitchell, Card and Hamilton (276, 278), and Halnan (129) have carried out slaughter tests and chemical analyses of different breeds of poultry at various ages. The percentage of ash in the bird's body rises rapidly during the first seven weeks, and then shows a gradual increase to 40 or 45 weeks. In the case of the pullet, a small decrease occurs at the onset of egg production, probably due to the extra requirement and mobilization for egg production. The percentage ash of cockerels is generally higher than that of pullets. It also appears that the percentage ash of heavy breeds (meat production) is lower than that of light breeds (egg

TABLE 1.—MINERALS IN AN AVERAGE EGG*

	Grams.
Calcium	1.975
Magnesium	0.027
Potassium	0.067
Sodium	0 073
Phosphorus	0 115
Sulphur	0.114
Chlorine	0.088
Iron	0.001

* Data of Halnan.

production) at the same age, indicating that "meat" breeds carry a higher proportion of meat to bone than the "egg" breeds. The distribution of minerals in various parts of the hen's body has been studied by Bernardi and Schwarz (14, 15).

Halnan's detailed analysis of 9-months old Light Sussex is shown in Table 2. Kaupp (201a) gave the mineral content of chicks at various ages.

TABLE 2.—COMPOSITION OF FAT-FREE, DRY MATTER*

—	Cockerel		Pullet	
	Flesh and offal	Bones	Flesh and offal	Bones
	%	%	%	%
Ash	5.50	38 88	4.98	40.50
	grams	grams	grams	grams
Ash	17.640	68.740	14.220	55 890
Phosphorus	2.848	11 600	2 418	9 880
Sulphur	3.733	0 922	3.160	0.742
Calcium	0.430	25.680	0.345	20 770
Magnesium	0.478	0.807	0.374	0.624
Potassium	4.778	0.787	3.630	0.566
Sodium	1.443	0.713	1.113	0 595
Chlorine	2.283	0 817	1.996	0 552
Iron	0.131	0.030	0.128	0.034

* Data of Halnan.

The distribution of minerals during embryonic development has been studied by Mankin (249), Horning and Scott (176), and by Leubir and Poulant (235).

Spectrographic analyses of eggs and tissues were carried out by Drea (416), showing that a number of elements pass from the feed into the blood, from there into the egg and finally into the chick's tissues and blood. These were aluminium, barium, calcium, copper, iron, magnesium, phosphorus, potassium, rubidium, silicon, sodium, strontium, titanium, and vanadium. Manganese and zinc though present in the hen's ration were absent from the chick's blood, but present in all organs but one.

Of the "trace" elements, barium, iron, strontium and vanadium were more concentrated in the blood and/or egg than in the feed, indicating some physiological importance. Boron was found only in egg yolk, silver was present in the egg, but fluorine was only found in one femur. Chromium, lead and molybdenum were present in the feed and in the hen's blood, but were not constantly present in the eggs.

In a similar study of eggs made in this laboratory through the co-operation of the Hospital for Sick Children, Toronto, all eggs were found to contain large amounts of sodium, calcium, magnesium, potassium and phosphorus, appreciable amounts of iron and silver, and traces of manganese, lead, tin, rubidium, strontium and chromium. Eggs from hens fed on the usual feedstuffs and those fed on a simplified diet including grass ash contained traces of aluminium, whereas without grass ash none of this

element could be detected. The "grass ash" eggs also contained cadmium barium and caesium.

Periodic analyses of bone in normal and abnormal chicks have been made by Russell and Massengale (331), Miller, Dutcher and Knandel (273), Harshaw, Fritz and Titus (139), and Elvehjem and Kline (100). The percentage of bone ash increases from 30 to 36% during the first week, and, in the presence of ample vitamin D continues to increase to 40 to 42% at six weeks. It would appear that these figures for the average ash content of chick bones should not be considered too seriously since the tentative A.O.A.C. method for the bioassay of vitamin D carriers for poultry feeding requires, for satisfactory calcification, an average bone ash content exceeding 45% at four weeks. On a rachitogenic diet the ash content drops to 27 to 29% at five weeks. According to Holmes, Pigott and Moore (173), using Rhode Island Red chicks, and Schroeder (341), using White Leghorns, there is a sex difference in the bone calcification, the bones of females having a higher ash content than those of males. Results of analyses in our laboratory with Barred Plymouth Rock chicks carried on for some years show the reverse, the bones of the males having the higher ash content. Whether this is due to breed difference is an open question. The procedure used also may be responsible. The procedure in analyzing bones has been discussed by St. John, Kempf and Bond (362), Lachat (222), and Bethke and Record (22). According to Lachat (220), this sex difference does not appear on vitamin D deficient diets. Later, Lachat (223), and Lachat and Halvarson (224) reported that there was an association between body weight and bone ash content. On the same ration, faster growing birds not only develop greater amounts of skeleton than slower growing birds, but the relative amount of minerals deposited in the skeleton is greater for the former. This finding is contrary to the conclusion of Harshaw, Fritz and Titus (139) that the percentage of ash in the bones of slower-growing birds is greater than that in the bones of faster-growing birds, whose rate of gain is normal. Limited data from our laboratory would support the latter conclusions. It is obvious that there is some complicating factor which, as yet, has not been controlled These findings, emphasize the necessity of further research on this fundamental problem. If abnormal bone formation is to be studied with any reasonable surety of success, it is imperative to have some general agreement as to what is normal bone development. In the author's opinion, until such time as it is generally realized that the first four weeks are an insignificant period for such studies, little real progress will be made. Many skeletal changes occur long after this period. He further questions whether four-week assays are fundamentally sound.

Lachat and Halvarson (224) concluded that vitamin D deficiency more seriously affects growth and calcification in females than in males, even though the former utilize the vitamin more efficiently, and reversal of normal sex differences in calcification may occur. The works of Buckner and Martin (35), Buckner, Martin and Insko (37), Wilgus (404) and Holmes, Pigott and Campbell (170) show that calcium and phosphorus are deposited in a fairly constant ratio (approximately 2 to 1) regardless of the completeness of bone development. Pearl (310) has reported a sex differentiation in the effect of calcium salts, using calcium lactate and

calcium lactophosphate. Van der Hoorn and Branion (384, 385) were able to cause a stimulation in the growth of females by the use of grass ash.

In the author's laboratory, in collaboration with H. LeMasurier of Toronto, a roentgen ray study of the skeletal development of various breeds of poultry at weekly intervals during the growing period up to the onset of egg production is being carried on. The results, although by no means complete, show that this field is very fruitful and indicate clearly that our knowledge of avian bone development is rather fragmentary.

In normal chicks the level of serum Ca is approximately 10–12 mg. per 100 cc. and inorganic P about 4–6 mg. However, various workers have reported widely varying values for the inorganic blood phosphorus. These differences can be accounted for, at least in part, by different analytical technique; by differences in the calcium and phosphorus content of the ration, cf. Massengale and Nussmeier (255), Heller, Hunter and Thompson (152) and Heller, Zimmerman and Thompson (157); and by variations in the source and amount of the antirachitic vitamin, cf. Steenbock, Hart, Jones and Black (358), Ackerson, Blish and Mussehl (1), Hughes and Titus (178), and Murphy, Hunter and Knandel (286), and numerous other workers. In this connection, it should be pointed out that Bills, Massengale, McDonald and Wirick (23), have shown that the vitamin D of irradiated ergosterol raises the calcium and phosphorus of chicken serum more effectively than it promotes calcification, whereas the vitamin D of cod liver oil promotes calcification more than it elevates the serum calcium and phosphorus. The age of the chicken is also a factor. Elvehjem and Kline (100), Hall and King (125), Harshaw, Fritz and Titus (139), and Greenberg, Larson, Pearson and Burmester (120) have made weekly blood analyses for calcium and phosphorus. The blood calcium may drop slightly from a level of 13–14 mg. per 100 cc. at two weeks to 10–11 mg. at six weeks, although all workers are not agreed on this point. The inorganic phosphorus level progressively decreases with increasing age. Unfortunately the results of blood analyses for calcium and phosphorus are not comparable since determinations have been made on whole blood, some on plasma, and others on serum.

Although the chicken is very resistant to hypervitaminosis D, excessive amounts do produce some changes in young birds. Hall and King (125), and Steenbock, Kletzien and Halpin (359) have observed a rise in serum calcium. Similar findings were obtained by Massengale and Nussmeier (255) with a ration containing only 0.1% of calcium. Hall and King (125, 126) found no deviation from normal in the percentage of ash and calcium in the bones, but histological examination showed imperfect calcification which was less marked when the irradiated ergosterol was fed with calcium phosphate. The inorganic phosphorus may decrease or show only slight changes.

Calcium exists in the blood in various forms. Presumably the inorganic calcium of the serum measures practically all the calcium of the blood, since the cells are almost devoid of calcium and practically all forms are transformed into and measured by the usual methods for inorganic calcium. The inorganic calcium can be subdivided into diffusible and non-diffusible. The diffusible fraction exists as readily ionizable salts, while the remainder is bound to protein. Some workers prefer to partition

the blood calcium into (1) an absorbable diffusible fraction, (2) a non-absorbable diffusible, (3) a non-diffusible absorbable, and (4) a non-diffusible, non-absorbable fraction. Other workers use the term "filtrable" in place of "diffusible".

Phosphorus is present, not only in the plasma but also in the cells, and owing to the fact that the red corpuscles of birds are nucleated, with resulting nucleoproteins containing phosphorus, the total phosphorus of fowl's blood is 3–4 times that of mammalian blood. Inorganic phosphorus constitutes but a small fraction of the total phosphorus. The phosphorus compounds of the blood can be subdivided into two main groups: (1) acid-soluble which includes inorganic, nucleoproteins, nucleotides and phosphate esters, and (2) alcohol-ether soluble or lipid-phosphorus.

Variations in these different fractions are not proportional as shown in Table 3 and as will be pointed out later in relation to ovulation. It seems possible that determinations of inorganic blood calcium and phosphorus which disregard these other fractions, have retarded the disclosure of more fundamental facts with regard to the influence of calcium and phosphorus on metabolism in poultry.

TABLE 3.--PHOSPHORUS DISTRIBUTION (MG. PER 100 CC.)*

—	Total P	Cell P				Plasma P			
		Total	Lipid	Inorganic	Acid soluble	Total	Lipid	Inorganic	Acid soluble
Normal	115 3	100 0	6 4	1 9	25 0	15 3	9 1	5 9	4 5
Osteoporotic	119 6	106 8	6 3	2 9	27 8	12 9	6 9	4 9	5.4

* Data of Heller, Paul and Thompson.

It is not easy to decide whether a disease, particularly abnormal bone development, is due to a mineral deficiency in the ration, or whether it is due to some fault in the physiological mechanisms for utilizing the mineral; the same pathological picture may result from apparently different causes, while different diseases may appear to arise from the same cause. Three types of disease must be distinguished due to (1) a deficiency of minerals in the diet—acalcicosis (calcium-deficiency), aphosphorosis (phosphorus-deficiency), etc.; (2) a deficiency in factors influencing mineral metabolism in the diet—avitaminosis etc.; and (3) a failure in the physiological mechanisms in the body of the bird which affect mineral metabolism.

It should also be pointed out that low mineral content of the blood may be associated with low mineral content of the ration but there is no necessary connection in some instances. The level of serum calcium is under the influence of a rigorous physiological controlling mechanism, the parathyroid glands, which produce a hormone, operating in association with the nervous system, and co-operating with the organs of storage, absorption and excretion (bone, intestines and kidneys), which, unless the regulatory mechanism breaks down (Hutt and Boyd, 186), maintain the physiologically normal level of calcium in the blood. The level of plasma phosphate is not under such control, or at least, not to the same extent.

Although hypophosphataemia (low blood phosphorus) is characteristic of either phosphorus deficiency in the ration or failure of the bird to absorb and utilize the phosphorus of the ration, hypocalcaemia does not always indicate a calcium deficiency.

Moreover, it seems evident that the time has been reached in a study of the mineral requirements of poultry, when the co-operation of the physiologist, particularly in relation to hormones such as parathormone, but also those hormones which influence egg production, and of the histologist, in relation to bone studies, must be sought. It is extremely doubtful if our present "standard" diets for the production of rickets in chicks produce rickets. True rickets is a phosphorus deficiency disease—be that deficiency produced as it may. Most, if not all, chicks suffering from experimentally produced "rickets", show deviations from normal in both blood calcium and phosphorus. Rickets should result in hypophosphataemia with normal blood calcium. As McGowan and Emslie (264) have pointed out there is no definite proof in the literature of the production of rickets, the evidence indicating osteoporosis. From a practical viewpoint this may not be important, since vitamin D therapy apparently prevents both conditions, but from fundamental considerations, a morphological study of the changes in bone seems essential. In this connection it might be noted that Oberling and Guerin (294, 295, 296) have described lesions of osteitis fibrosa in chicks.

2. MINERAL CONTENT OF FEEDINGSTUFFS

The extent to which ordinary feedingstuffs furnish minerals can be judged from the following table showing the average mineral content of the common poultry feeds gleaned from various sources. It should be clearly borne in mind, in using an average figure for the mineral content of a feed, that the amount of these minerals in any particular lot of feed may differ considerably from the average. The composition of feedingstuffs is greatly influenced by the source and method of processing, by the stage of maturity, and by the water content and amount of plant food, especially nitrogen, calcium, phosphorus and potash in the soil.

TABLE 4.—AVERAGE PER CENT MINERAL CONTENT OF FEEDS

Feed	Ash	Calcium	Phosphorus	Magnesium	Sodium	Potassium	Chlorine
Alfalfa meal	7.6	1.23	0.20	0.40	0.45	1.91	0.15
Alfalfa leaf meal	11.1	2.23	0.30	—	0.11	2.04	0.54
Barley	2 8	0 06	0.37	0.15	0.08	0.49	0.49
Blood meal	3.4	0 28	0.22	0.06	0.48	0.10	0.50
Bone meal (steamed)	80.2	30.26	14.18	0.81	0.48	0.15	0.06
Bone meal (raw)	61.8	23 83	11.00	—	—	—	—
Buckwheat	2.0	0 04	0.29	—	—	0.27	—
Buttermilk (dried)	10.1	1.34	0.81	0.14	0.51	0.71	1.21
Cod liver meal	3.1	0.13	0.75	—	—	—	—
Corn	1.3	0.01	0.27	0.12	0.02	0.32	0.04
Corn gluten feed	4.9	0.18	0.69	0.43	1.03	1.13	0.22
Crab meal	39.5	13.06	0.51	—	—	1.90	—
Distiller's corn grains (dried)	2.1	0.05	0.31	0.05	0.15	0 01	0.07
Distiller's rye grains (dried)	3.3	0.13	0.44	0.20	0.08	0.04	0.03

TABLE 4.—AVERAGE PER CENT MINERAL CONTENT OF FEEDS—*Concluded*

Feed	Ash	Calcium	Phosphorus	Magnesium	Sodium	Potassium	Chlorine
Fish meal (65–70% protein)	14.8	4.08	2.85	0.67	0.40	—	0.60
Fish meal (60–65% protein)	21.0	7.19	3.79	0.21	1.49	0.92	1.35
Fish meal (55–60% protein)	22.6	7.32	3.89	0.22	1.58	0.32	1.65
Fish meal (herring)	14.2	4.32	2.85	0.21	0.74	0.49	0.47
Fish meal (pilchard)	16.5	8.34	4.54	0.28	0.65	0.69	0.42
Hominy	1.6	0.02	0.32	0.02	0.13	0.36	0.06
Limestone	—	38 97	—	—	—	—	—
Linseed meal (old process)	5.6	0.38	0.88	0.58	1 04	1.32	0.44
Linseed meal (new process)	5.6	0.36	0 71	—	—	—	—
Meat meal (60% protein)	17.2	5 42	2.85	—	—	0.55	—
Meat meal (55% protein)	23.9	8.18	4.09	1 17	0.60	1.43	0.46
Meat meal (50% protein)	26 9	10.96	5.16	—	—	—	—
Oats	3 4	0 10	0.39	0 16	0 16	0.46	0.07
Oat middlings	4.1	—	0.56	—	—	0 57	—
Oyster shell	—	37.95	—	—	—	—	—
Rye	2.0	0 05	0 36	—	0 04	0 54	0.02
Skimmilk (dried)	7 6	1.29	0.97	—	—	1 46	—
Soyabean oil meal	5 6	0.26	0.73	0 28	—	2.20	0 07
Tankage (55–60% protein)	21 1	7.01	3.42	—	—	0 55	—
Tankage (50–55% pro tein)	27.1	11 70	5 15	—	—	—	—
Wheat	1.8	0 06	0 39	0.16	0 04	0 44	0 10
Wheat bran	5 8	0 12	1 26	0.58	0 09	1 23	0.07
Wheat middlings	3 9	0.10	0 88	0.40	0.14	1.12	0.04
Wheat shorts	3 7	—	—	—	—	—	—
Wheat feed flour	2 8	0 08	0 64	—	—	—	—
Whey (dried)	17 7	1 18	0 66	—	—	—	—

The important minerals in poultry nutrition, from a quantitative viewpoint, are calcium, phosphorus, chlorine, sodium, potassium and magnesium. In addition, iron, copper, manganese, iodine and probably others are required. Foods of plant origin are low in chlorine and sodium and, with the exception of the legumes, are low in calcium. Since the rations of poultry contain a fairly high percentage of cereal grains and their byproducts which are fairly high in phosphorus, there is little or no danger of aphosphorosis in poultry. Calcium is the mineral most likely to be deficient in poultry rations. It is possible that the "availability" of the phosphorus in cereals, one-half of which is phytin, may need some consideration. Phytin is the calcium-magnesium salt of inositol phosphoric acid and presumably the digestive juices of the fowl contain no enzyme capable of hydrolyzing the compound. Some feedstuffs contain an enzyme which can digest the substance. However, the fact that practical experience over a period of years has shown no indication of phosphorus being a limiting factor in poultry production, would suggest that either phytin is available to poultry or else the present accepted levels of phosphorus in the rations are so in excess of the requirement that the "non-

availability" of this salt is overcome. Feeds of animal origin are rich in all of the more important minerals required by birds and compensate for the deficiencies of foods of plant origin. The beneficial results attendant upon the inclusion of protein supplements of animal origin in poultry rations is due not only to the amount and quality of the protein which they furnish but to their mineral and, in some instances, to their vitamin content, as well. Concentrates such as meat meal and fish meal add appreciable quantities of minerals, particularly calcium and phosphorus, to rations. This fact is often disregarded and disastrous amounts of "mineral" supplements, such as bone meal or limestone, are added to the ration. The resultant excess amount of these minerals is decidedly detrimental.

It would appear that, in practical rations, only five minerals need consideration, namely calcium, phosphorus, sodium, chlorine and iodine. Halnan (129), from comparative analyses, has calculated that the body of the hen contains sufficient calcium for the formation of 10.7 two-ounce eggs, magnesium for 37.0, potassium for 62.6, sodium for 23.3, phosphorus for 107.0, sulphur for 34.2, chlorine for 29.0 and iron for 162.0. Jull (197) calculated that a hen fed on wheat alone would have to eat 12 pounds of wheat to supply the necessary calcium required for one egg, ½ pound to supply the necessary sodium and 3½ ounces to supply the chlorine. Lippincott and Card (236) calculated that a flock of 400 hens weighing 4 pounds each and in 50% production would require 404 pounds of corn daily to supply the calcium requirement for maintenance alone, whereas the eggs would necessitate over 6 tons of corn daily. These figures, although reducing the matter to an absurdity, nevertheless emphasize the necessity of supplementing cereal grains with minerals from some source, as well as pointing out the limitations of body reserves.

It was rather startling to the reviewer to discover that little or no work has been done with reference to the optimum total mineral content of poultry rations. Admittedly, the total mineral content of a ration, taken by itself, may be very misleading, since the results would depend upon the kind and amount of the individual minerals therein. However, it would seem possible by the use of certain basal diets together with the use of a "complete" mineral mixture to arrive at some base line. From a survey of results with simplified diets both in our own and other laboratories, and by a consideration of the voluminous literature dealing with perosis, the optimum level for chicks would seem to lie between 4 and 6%. A total mineral content in excess of 6% usually results in bone disorders. Parkhurst and McMurray (305) encountered perosis on a diet analyzing only 3.8% ash, but it only contained 0.19% calcium. The mineral requirements of laying hens are largely met in practise by allowing them unlimited access to oyster shell and bone meal.

3. CALCIUM AND PHOSPHORUS REQUIREMENTS

(a) General

In addition to the functions of calcium and its interrelationship with other minerals, which have been pointed out, it is necessary for the coagulation of blood and the clotting of milk during digestion. Phosphorus, in addition to its function in bone and tissue formation, and in the regulation

of the pH of the body fluids, is of vital importance in metabolism. Phosphorization of carbohydrates and fats is the primary step in their intermediate metabolism. Buckner and Harms (32a) investigated the effect of calcium supplements on digestibility.

(b) Calcium and Phosphorus for Growth and Bone Formation

The ratio between the amount of calcium and that of phosphorus in the ration would seem to be of some importance, since an excess of one results in depletion of the other for excretory purposes. An optimum Ca : P ratio in the ration apparently lessens the requirement for vitamin D, but with a vitamin D deficiency no Ca : P ratio will produce good bone. Moreover, some investigators seem to have lost sight of the fact that the absolute amounts of calcium and phosphorus often are more important, the ratio occurring as a natural sequence. It is quite possible to devise a ration with a good Ca : P ratio, but furnishing inadequate or excessive amounts of both minerals.

Bethke, Kennard, Kick and Zinzalian (21) concluded that a Ca : P ratio of 3–4 : 1 was optimum for calcification. A close inspection of their data indicates that the level of calcium in the ration had more effect than the ratio. Although Hart, Scott, Kline and Halpin (142) are often quoted as advocating a wide ratio, they concluded that, in the presence of adequate vitamin D, with the calcium varying from 0.61 to 1.13% and with 0.30% phosphorus, the optimum ratio was 2–4 : 1. With minimum vitamin D the best calcification was obtained with 2.49 to 2.71% calcium and 0.66 to 0.83% phosphorus, giving a ratio of about 3–4 : 1. Tully, Hauge, Carrick and Roberts (380, 381), Massengale (254), Marcq and Dervyst (250), and Holmes and Pigott (169) have dealt with this problem. Bethke, Kennard and Kick (20) obtained their best results with 0.86% Ca and 0.44% P, with a ratio of about 2 : 1. Wilgus (404) concluded that the Ca : P ratio may vary between 1–2 : 1; 2.5 : 1 was borderline; and 3.3 : 1 was disastrous. This problem has also been studied by Parkhurst and McMurray (304). In discussing this question, Titus, McNally and Hilberg (374) concluded that there was no common optimum ratio for all rations and that it depended partially on the acid-base balance of the diet. Mussehl and Ackerson (287) also concluded that the Ca : P ratio was not the only factor involved in bone formation and growth. It would seem feasible to conclude that with adequate vitamin D and reasonable levels of calcium and phosphorus in the ration, the Ca : P ratio may vary between 1–3 : 1 with 2 : 1 optimal.

The minimum calcium requirement for young chicks has been set by Wilgus (404) as 0.66%, although practical mashes generally contain about 1.2%; by Bethke, Kennard, Kick and Zinzalian (21) at 0.96–1.00% or or less; between 0.66 and 0.86% by Bethke, Kennard and Kick (20); at about 0.71 to 0.75% by Hart, Scott, Kline and Halpin (142); less than 0.94% by Supplee (367); 1.07 to 2.14% to eight weeks of age and 0.93 to 1.36% to twelve weeks by Sherwood (347) and 1.0 to 1.8% by Carver, Brunstad, St. John, Frasier and Athow (58). From analytical data, Mitchell, Hamilton and Card (277, 278) devised a calcium feeding standard for White Leghorn chicks varying from 0.11 grams per day at one-half

pound body weight to 0.14 grams at 5 pounds for cockerels. For pullets they recommend 0.10 grams per day at one-half pound body weight increasing to 0.19 grams at two pounds and then decreasing to 0.08 grams at 5 pounds body weight. The calcium requirements for growing turkeys range from 0.70 to 0.84% according to Mussehl and Ackerson (288).

The minimum phosphorus requirements have been reported as 0.50% or less by Wilgus (404), between 0.37 and 0.60% by Bethke, Kennard, Kick, and Zinzalian (21); Hart, Scott, Kline and Halpin (142) indicated that 0.30 to 0.42% was borderline; between 0.26 and 0.50% by Supplee (367); by Watkins and Mitchell (394) as less than 0.50%; while Sherwood (347) recommends 0.65 to 0.87% for chicks up to eight weeks and 0.48 to 0.53% to twelve weeks.

The calcium and phosphorus requirements have been studied also by Jull (195), Kupsch (219a), Gutowska (122a), and Kaupp (201).

TABLE 5.—CALCIUM AND PHOSPHORUS REQUIREMENTS FOR CHICKS OF LIGHT BREEDS*

	Calcium requirements			Phosphorus requirements		
Body weight lbs.	Net requirement grams per day	Dietary calcium required grams per day	Necessary calcium in dry ration, per cent	Net requirements grams per day	Dietary phosphorus required grams per day	Necessary phosphorus in dry ration per cent
Pullets						
0.5	0.09	0.18	0.64	0.08	—	0.32
1.0	0.13	0.26	0.70	0.12	—	0.35
1.5	0.15	0.30	0.68	0.15	—	0.34
2.0	0.15	0.30	0.59	0.16	—	0.31
3.0	0.12	0.24	0.39	0.15	—	0.25
4.0	0.05	0 10	0.14	0.07	—	0.07
Cockerels						
0 5	0.10	0.20	0.71	0 09	—	0.36
1.0	0 16	0.32	0.86	0.14	—	0.43
1.5	0.19	0.38	0.86	0.18	—	0.43
2.0	0 20	0.40	0.78	0.20	—	0.39
3.0	0.20	0.40	0.66	0.21	—	0.34
4.0	0.15	0.30	0.42	0.20	—	0.28
5.0	0.09	0.18	0.22	0.13	—	0.16

* Data of Mitchell and McLure.

Ackerson, Blish and Mussehl (2), using a ration containing 0.70% calcium and 0.81% phosphorus found that 43.4% of the calcium and 27.3% of the phosphorus intake was retained. Later, these workers (3) reported that utilization of phosphorus, the ration containing about 0.80% was unaffected by varying the calcium content of the diet, the retention being about 28%. The percentage of calcium retained was 35% when the diet contained 0.9%, 24% when the level of dietary calcium was 1.5%, and 13% when 2.3% was supplied.

From a resume of this evidence the minimum calcium requirement for growing chicks would seem to be about 0.70%, and that of phosphorus

as 0.40%. To provide a margin of safety, without danger of overdosage, practical chick rations probably should furnish about 1.0% calcium and 0.50% phosphorus. Mitchell and McClure (280) have estimated the requirements for growing Leghorn chicks as shown in Table 5. Larger breeds probably have somewhat greater requirements than this light breed. However, since their needs are expressed in percentage of dry matter in the ration, and larger breeds consume more feed, these percentage estimates would probably suffice.

(c) Calcium and Phosphorus for Laying Hens

The calcium requirements of the laying hen will depend on the number of eggs laid, the amount of calcium in the egg exceeding that of other minerals. An average egg contains approximately 2 grams of calcium, the greater part being present in the shell, only 0.026 gram being present in the yolk and 0.004 gram in the white. Compared with bone calcification, egg shell formation is an extremely rapid process. The calcium carbonate is secreted by the glands in the wall of the oviduct and according to Cruickshank (82) the process requires only 12 to 16 hours. The calcium is supplied by the circulating blood, since the oviduct itself has little or no reserve of calcium.

In the absence of a sufficient supply of calcium, egg production is lowered and may finally cease, the egg shells becoming progressively thinner. The serum calcium of the hen falls and there is a depletion of the calcium and phosphorus of the bones and a reduction in hatchability. Collier (69), Wheeler (399), Buckner and Martin (33), Buckner, Martin and Peter (42, 44, 45, 47, 50) and Buckner, Martin, and Insko (39) and Buckner, Martin, Pierce and Peter (51) have studied this problem. The percentage composition of the shell, however, remains constant showing that, like bone formation, if the mineral is deposited, it is laid down in the normal proportion. Deobald, Lease, Hart and Halpin (87) concluded that about 10% of the calcium stored in the bones may be called upon for egg shell formation. The phosphorus requirements are not greatly raised for egg production.

The calcium and phosphorus requirements of laying hens have not been the subject of as many studies as those of chicks. Norris, Heuser, Wilgus and Ringrose (293) concluded that 1.65% of calcium is just sufficient to meet the requirements as judged by egg production, shell strength and ash, and by the levels of calcium and phosphorus in the blood. On a ration containing about 1.8% calcium, 0.5% phosphorus was insufficient, but 0.75% was adequate. Miller and Bearse (271) using rations varying in calcium from 2.23 to 3.03%, and in phosphorus from 0.40 to 1.08%, concluded that egg production was influenced by the amount of phosphorus in the ration. They obtained the highest egg production with 0.80%. From their data, it would appear that 2.25% calcium was adequate or more than adequate. Mitchell and McClure (280) have prepared a standard for calcium and phosphorus feeding for laying hens, part of which is given in Table 6. Although it varies according to the rate of egg production it is based unfortunately upon a three-pound hen, a weight generally below that encountered in the field. Until more data

TABLE 6.—CALCIUM AND PHOSPHORUS REQUIREMENTS OF LAYING HENS*‡

Rate of egg production	Net calcium required, grams	Necessary calcium† in dry ration, per cent	Net phosphorus, grams	Necessary phosphorus† in dry ration, per cent
100	2.10	4.16	0.27	0.38
75	1.60	3.52	0.24	0.35
50	1.11	2.74	0.21	0.32
25	0.61	1.72	0.18	0.30
0	0.12	0.39	0.15	0.25

* Data of Mitchell and McClure.
† Based on 50% utilization.
‡ White Leghorn hen weighing three pounds.

are available, the safe practise would seem to be that of allowing the birds free access to such supplements as oyster shell or limestone and bone meal.

Titus, Byerly, Ellis and Nestler (372) in a series of experiments also investigated this requirement by varying the levels of calcium and phosphorus in diets fed to laying hens and pullets. In one series the phosphorus level was constant at 1.2% and the calcium was fed at 1.2, 3.0 and 5.4% levels; in another the phosphorus was maintained at 0.9% with the calcium at 0.9, 2.25 and 4.05%; in a third the phosphorus was constant at 1.2% and the calcium intake was 1.3, 3.0 and 5.4%. Their results establish the fact that the calcium requirement of pullets and hens is different and that a high level of calcium adversely affects the hatchability. In disagreement with the Washington results they concluded that the level of phosphorus intake had no effect on egg production. The "proper" quantity of calcium in the diet varied from 1.95% for crossbred hens to 2.20% for Leghorn pullets, when the phosphorus content was 0.9%.

The Beltsville workers have devised a formula for estimating the calcium requirement of laying birds. The equation is:

$$\mathrm{Ca} = \frac{1.292(PF - 10.8E) + 200E.}{F}$$

in which

Ca = the required percentage of calcium in the diet,
1.292 = the ratio of Ca to P in dicalcium phosphate,
P = the percentage of phosphorus in the diet,
F = the number of grams of feed consumed by a laying chicken during a year,
10.8 = 100 times the quantity (in grams) of phosphorus in the egg,
E = the number of eggs produced in one year,
200 = 100 times the quantity (in grams) of calcium in an average egg.

In the reviewer's opinion, the practice of mixing mineral supplements into laying mashes is to be condemned, since it does not make full allowance for variation in the rate of production, nor of size of egg. The method of controlling calcium intake, as outlined above, may be theoretically sound, but its application in practise is not feasible. Moreover, it is obvious

that such a method cannot be used by feed manufacturers, and the reviewer is doubtful if sufficient data on feed consumption, etc., is available to enable even the research worker to use the formula. After all, any such formula is based upon the flock average, and the high producers will be underfed, the low producers will be overfed—surely an unscientific procedure.

(d) Calcium and Phosphorus Metabolism During Production

(1) Calcium

With the onset of egg production the calcium content of the blood of the female may rise to double the normal concentration maintaining a high though variable average during the laying period, falling during moulting. In the male no such changes occur, the calcium level remaining constant at about 10 to 11 mg. per 100 cc. serum. Bell (10) found the calcium index in the case of a non-laying hen to vary between 0.9 and 1.3, whereas in the laying hen the variation was from 0.5 to 3.1. Buckner, Martin and Peter (46) and Buckner (32) showed that there was not enough calcium in the shell gland to account for all the calcium in the shell, and postulated a direct removal from the blood during shell formation. Hughes, Titus and Smits (179) showed that the level of calcium was much higher in laying hens—up to three times—than in immature pullets. Parhon (302) found an increase in serum calcium during laying which diminished with the onset of broodiness. Russell, Howard and Hess (330) reported that the serum calcium of hens lay between 13.0 and 26.7 mg. Ca per 100 cc. serum if an ovum greater than 1 cm. in diameter was present. When no ova were observed the level was between 7.5 and 13.0 mg. MacOwan (266) found that with a 1 gm. ovum the serum Ca was 13.4 mg., with ova weighing up to 30 gm. it was 23.5, while beyond this size of ovum the level was about 20.7 mg. per 100 cc.

Buckner, Martin and Hull (36) showed that the laying hen absorbed calcium at a rapid rate from the intestine, the calcium content of the blood in the anterior mesenteric vein being 2 to 2.5 mg. per 100 cc. higher than in the anterior mesenteric artery. This difference was not found in non-laying hens.

Charles and Hogben (61) could not correlate the level of serum calcium in the blood with the position of the egg in the oviduct. They found wide variations in the blood calcium when the egg was present in the oviduct, showing a range of 10.5 to 28.5 mg. However, they used a different hen for each determination, and the level of blood calcium varies greatly among individual hens. With no egg in the oviduct there was less variation, from 14.7 to 19.6 mg. Knowles, Hart and Halpin (215) reported a variation in the calcium in the blood of laying hens from one oviposition to another, using the same hen for each series of bleedings, but the maxima and minima were not constant for the same hen, the period of low level corresponding to the time for shell deposition, and the high level corresponding to the absence of a fully-formed egg in the shell gland. They also found, using one hen, a marked difference in the calcium level in the blood from the uterine artery and vein during shell deposition. However, Deobald, Lease, Hart and Halpin (87) repudiated these previous findings and stated that the calcium content in the blood of the individual hen was

nearly constant, varying only within narrow limits during a complete egg cycle, a finding substantiated by Feinberg, Hughes and Scott (106). Rochlina (328) has also studied this problem. In a recent study Deobald, Christiansen, Hart and Halpin (84) removed various parts and the entire oviduct from pullets. The blood calcium curve at maturity was normal, showing that the oviduct itself had no influence on the mobilization of calcium previous to laying.

Benjamin and Hess (11), Correll and Hughes (77), Taylor and Russell (370), and Laskowski (228, 229) have shown that the rise in total calcium is not associated with the diffusible calcium of the blood, which remains constant in laying and non-laying hens. The adsorbable diffusible fraction decreases slightly during egg production and the non-adsorbable fraction increases slightly, so that the level of total diffusible Ca remains the same. Both fractions of the non-diffusible Ca increase greatly, according to Benjamin and Hess (11), Paul (306), and Heller, Paul and Thompson (153). Greenberg, Larson, Pearson and Burmester (120) also concluded that the very large increase in the serum calcium level was confined almost exclusively to the non-diffusible fraction. The increment could only be partly accounted for by the formation of a colloidal form of calcium phosphate.

Calcium metabolism of the egg during incubation has been studied by Plimmer and Lowndes (318), Buckner, Martin and Peter (45), Gazzaniga (116), Insko and Lyons (188), Glaser and Piehler (117a), and by Kamachi (198).

(2) Phosphorus

As shown by Heller, Paul and Thompson (153), during the first five months the total P content of blood rises gradually from 110 mg. to about 115 mg. per 100 cc. With the onset of egg production there is a sudden increase to a level of 131 mg. which persists throughout production. Similar changes take place in the total P of cells and plasma, because of an increase in the lipoid fraction in both. Greenberg, Larson, Pearson and Burmester (120) verified the striking increase in the fat and phospholipid content of the blood during ovulation, as reported by Laurence and Riddle (231) and Warner and Edmund (393). Roepke and Hughes (329) and Laskowski (230) reported that while in non-laying hens and males the total P is equal to the sum of the lipoid and acid-soluble fractions, in the laying hen the total phosphorus is greater than the sum of the two, owing to the appearance of a new fraction, a phosphoprotein, having properties similar to vitellin. Presumably, the increase in lipoid phosphorus and the appearance of phosphoprotein is associated with the formation of yolk, which contains considerable lecithin and vitellin.

According to Laskowski (230) the inorganic blood phosphorus also increases during the laying period, although there is considerable individual variation. Roepke and Hughes (329) found a higher value for the inorganic P in the blood of laying as compared with non-laying hens, but it was somewhat below the value for males. Greenberg, Larson, Pearson and Burmester (120) reported an increase in inorganic serum phosphorus, which was directly correlated with the serum calcium level. Deobald, Christiansen, Hart and Halpin (84) reported that the total phosphorus in

the blood showed a direct correlation with the blood calcium curve, except at the high peak immediately preceding the laying period. Feinberg, Hughes and Scott (106) reported a marked rise during the period of shell deposition. Heller, Paul and Thompson (153) and Benjamin and Hess (11) claimed that the inorganic phosphorus was similar in cockerels and laying hens.

Benjamin and Hess (11) reported that the filtrability of the inorganic P was very low and is only very slightly reduced in hypercalcaemia, whereas Laskowski (230) found that inorganic P in the plasma of immature pullets was almost entirely diffusible, but that this diffusibility was decreased one half in laying hens. Similar results were obtained by Roepke and Hughes (329), Grollman (121) and Greenberg, Larson, Pearson and Burmester (120). Their values are shown in Table 7.

The phosphorus metabolism of the developing embryo has been studied by Plimmer and Scott (317), Baldwin and Needham (9), Insko and Lyons (188), Kamachi (198) and by Schmidt (340)

(e) Phosphatase

Phosphatase is an enzyme which effects the hydrolysis of certain phosphoric esters, magnesium acting as a co-enzyme, present in blood, bone, intestines and kidney This enzyme is considered to be an active agent in ossification, bringing about the hydrolysis of these esters in the blood and thereby raising the concentration of inorganic phosphate so that calcium phosphate is deposited Emslie (101) Schecter (334), and Common (73, 75) have found that the plasma phosphatase of chicks suffering from experimentally producted "rickets" is increased above normal. Confirmatory evidence has been obtained in the reviewer's laboratory. This

TABLE 7 —PARTITION OF THE CALCIUM AND INORGANIC PHOSPHORUS IN THE BLOOD SERUM OF THE FOWL*

—	Calcium				Inorganic phosphorus		
	Age	Total	Diffusible	Non-diffusible	Total	Diffusible	Non-diffusible
Non laying	½ month	11 3	6 4	4 9	10 0	8 5	1 5
	1 month	12 0	7 0	5 0	8 8	7 4	1 4
	2 months	12 9	7 0	5 9	8 7	5 8	2 9
	3 months	12 0	6 9	5 1	6 9	5 4	1 5
	4 months	12 1	6 8	5 3	6 4	5 0	1 4
	5½ months	11 5	9 6	1 9	5 5	5 6	0 0
Pre laying	6–7½ months	31 6	8 8	22 8	7 4	3 6	3 8
Laying	6½–8 months	23 7	9 4	14 3	6 1	3 9	2 2

* Data of Greenberg, Larsen, Pearson and Burmester

finding is important since Branion (30) has shown that the plasma phosphatase of rachitic rats is generally decreased. Since it is well established that "rickets" can be induced in chicks by deprivation of vitamin D alone, whereas to produce the disease in rats it is necessary to deprive them not

only of the vitamin but also to upset the Ca : P ratio of the diet, it is not surprising that the two conditions are fundamentally dissimilar. Moreover, Kay (203) has shown that in bone disease of humans the plasma phosphatase is increased.

Common (75) found that the serum phosphatase while showing considerable individual variation, was significantly higher in laying than in non-laying hens or cocks. Auchinachie and Emslie (8) did not observe any difference in the values for "strictly normal" laying and non-laying hens but with birds confined indoors with inadequate vitamin D, laying pullets showed a much higher plasma phosphatase value. This would support the contention that, under certain conditions at least, the laying hen draws on her skeleton for calcium, with resultant osteoporosis (Doyle, 89). Hall and King (125) found that the bone phosphatase content of rachitic chicks was about twice the normal value whereas in hypervitaminosis D it was reduced to one-sixth normal.

(f) Parathyroid Glands

Since the parathyroid glands, two small bodies at the posterior pole of each thyroid gland, produce a hormone concerned in the regulation of blood calcium, it does not seem amiss to consider them in this review.

Doyle (89) and Hogan, Shrewsbury and Kempster (166) noted an enlargement of the parathyroid, up to 5 to 8 times the normal size in the absence of vitamin D. According to Higgins and Sheard (162) and Sheard and Higgins (345), both hyperplasia and hypertrophy exist, the former being more marked. In severe cases, the parenchyma shows regression and cysts develop, according to Higgins, Sheard and Wilder (163) and Nonidez and Goodale (292). When the rachitic birds are irradiated the parathyroids return to normal size.

Collip (70) was unable to demonstrate any effects from the injection of parathormone upon non-laying hens, but Knowles, Hart and Halpin (215) were able to show that chickens respond to a single, large injection (30–60 units) of the hormone, but in order to ascertain the rise the blood samples must be taken early after injection. They concluded that the rise in blood calcium as a pullet comes into production is due primarily to increased activity of the parathyroid. Deobald, Lease, Hart and Halpin (87) corroborated this finding but observed that long continued injections of the hormone into hens starved of calcium was without effect. Deobald, Christiansen, Hart and Halpin (84) reaffirmed this conclusion, and further reported that hens on a low calcium ration did not respond even when calcium carbonate was administered previously. Low calcium and low phosphorus diets resulted in similar blood calcium curves. Both rations inhibited egg production and both caused a negative reaction to parathormone. Altman (6) obtained a rise in serum calcium in non-laying birds by injections of parathyroid extract, progynon B, egg yolk, liver extract and to a still higher level by simultaneous injection of anterior pituitary extract and egg yolk. Injection of the follicle-stimulating fraction of the anterior pituitary with parathyroid extract gave no greater rise in serum Ca than parathyroid alone. Egg yolk raised the blood calcium of capons. The blood calcium was depressed by injections of the thyrotropic hormone of the anterior pituitary and by simultaneous injections of extracts

of the whole anterior pituitary and parathyroid, while anterior pituitary extract alone was without any effect. The elevated blood calcium level of laying hens was decreased by injections of progynon B and by egg yolk.

By histological investigation, Sun and MacOwan (366) found that the gland in laying hens differed from that of the non-laying hen. In the former, the cells were larger, less closely packed, with some degree of vacuolation. Later MacOwan (266) confirmed this and was able, by injections of parathormone, to increase the serum calcium in pullets, but obtained a varied response with non-laying hens and no response in males.

(g) Mineral Balance Experiments

Although mineral "balance" or retention experiments with fowl have yielded some valuable results in calcium and phosphorus metabolism, only very few such studies have been carried out. The technical difficulties involved are great. Such studies are complicated by the fact that these minerals are excreted into the intestine, that the urine and faeces are voided together, and by the fact that calcium may remain for sometime in the gizzard in the form of oyster shell or certain grits—to say nothing of the practical difficulties in preventing food spillage and egg breakage. Moreover, even with hens in steady production, it normally takes from 21 to 27 hours for the egg to pass through the oviduct, and it may be "held" for some hours longer. The question arises as to which day the calcium and phosphorus in an egg laid should be credited. A "short cycle" as against a "long cycle" hen further complicates the problem. Again, most of the phosphorus is in the yolk, and the time necessary for the "maturing" of the yolk is also involved. It should be evident that one should not be too critical of any discrepancies in results of such studies which arise. In fact, it is astonishing that such good agreement has resulted.

The hen has no large reserve of calcium or phosphorus for egg formation, and the storage of these two elements occurs about one week prior to the onset of laying according to Halnan (127), or about two weeks according to Common (71). This increased demand is met by increased retention from the food, the percentage retention of calcium rising from 20 to 70%, provided there is an adequate dietary supply of both calcium and salt. According to Stewart (360), Osawa (301), and Mayneord (261) the calcium in egg shell is mainly present as crystals of calcite. Halnan (129) offers an ingenious explanation for the mobilization of calcium for egg shell formation and its subsequent deposition. He postulates that the immediate precursor of the calcium carbonate of egg shell is calcium bicarbonate. The calcium absorbed from the gut increases the blood calcium content, which is maintained partly by the hormone of the parathyroids, acting by withdrawal of calcium from the bones and partly by the antirachitic vitamin by protecting the blood calcium from excretion. The larger part of this calcium is converted to a non-diffusible calcium-phosphorus complex which can be conveniently transported without upsetting the normal ionic concentration of the blood serum. The calcium secreted by the shell gland from the diffusible calcium of the blood serum reduces the ionic concentration of the serum calcium, thus favouring the break up of the non-diffusible calcium-phosphorus-protein complex. The diffusible

calcium concentration of the serum is restored to normal and the excess diffusible phosphate is excreted. Partial support for this theory is available from the finding of Halnan (127), Russell and McDonald (332), and Common (71) that there is greatly increased excretion of phosphorus during egg production, which the last worker correlated with the period of shell formation. Halnan (127) thought the phosphorus excretion during egg production was due to the formation of egg fat from phosphatids. Believing that the amount of calcium which could be held in reserve in the blood was small, Common (71) suggested that the skeleton acts as a temporary storehouse for this element. Withdrawal of CaO from the bones would necessitate the removal of equivalent amounts of P_2O_5 as a result of the breakdown of $Ca_3(PO_4)_2$. His later studies (72, 74) indicated that the voiding of phosphorus is dependent upon the amount of calcium in the diet, since in the presence of an adequate supply, heavy phosphorus excretion may not accompany egg production. It would seem that removal of calcium from the bones is not necessary for a hen adequately supplied with calcium carbonate and vitamin D. However, it is probable that this process does go on to some extent, particularly in the case of the heavy producer, or at the peak of production. Under such circumstances, it is doubtful if the hen would be able to absorb and assimilate calcium from the gut fast enough to meet the heavy requirement for shell formation. During the moult or in periods of low production the skeletal reserve would be restored. We have found that laying birds, although having unlimited access to oyster shell, consume appreciable amounts of bone meal in addition, suggesting that there is some physiological requirement for phosphorus during egg production. The bones of a laying bird, ingesting suboptimal amounts of calcium or vitamin D presumably are osteoporotic. Schmidt (339) has also investigated calcium and phosphorus retention. This problem has also been discussed by MacDonald and Orr (239).

With regard to the combination in which calcium and phosphorus occur in the excreta, Halnan (127) considered that during non-laying, the actual values for excreta calcium agreed with that theoretically required to combine as tricalcium phosphate with all the phosphorus in the droppings. During the laying periods the phosphorus excretion was in excess of that required for such combination. Russell and McDonald (332) found that during production there was more phosphorus excreted than is necessary to form tricalcium phosphate, and during non-production less than required to form this compound with the excretory calcium. Knowles, Watkin and Hendry (216), using non-layers, concluded that the phosphorus was present as dicalcium phosphate, the remaining calcium being present as the carbonate. Common's (72) experiments show that, during egg laying, and in only a few instances during non-production, all the phosphorus could not have been present as dicalcium phosphate, and generally, there was insufficient calcium to combine with all the calcium as the monocalcium salt. He concluded that the extra phosphorus was excreted in the urine, probably as a soluble ammonium salt. Morgan (281) concluded that pullets, fed on the usual laying ration, receive sufficient phosphorus to meet their requirements as indicated by the cumulative positive balance. During heavy egg production, most of the birds were in negative calcium balance, particularly during the first months of production.

(h) "Availability" of Various Ca and P Compounds

As was pointed out, the term "availability" means very little; nevertheless it is used here in the practical sense to indicate whether various calcium and phosphorus compounds will serve as a source of these elements for bone formation or egg production. Bethke, Kennard and Kick (20), using rations containing 0 86% calcium, found no difference in the availability of the calcium in the carbonate, sulphate, lactate and both di- and tricalcium phosphate salts or the commonly used minerals of limestone, steamed bone meal, rock phosphate, phosphatic limestone, or oyster shells for bone formation. As will be pointed out later, rock phosphate and phosphatic limestone, often give unsatisfactory results due to their fluorine content. Similarly some limestones, particularly dolomite, are inferior due to their magnesium content. Phosphatic limestones contain varying proportions of calcium phosphate and carbonate, but "rock phosphate" usually is applied to material containing from 60 to 75% calcium phosphate whereas "phosphatic" limestone contains about one-third as much phosphorus. Lewis (234) observed that bone meal was superior to inorganic phosphate. Buckner and Martin (35) reported that tricalcium phosphate, fed alone or with calcium sulphate or carbonate gave increased growth and bone development, although it did not materially influence the percentage of ash, calcium and phosphorus in the bone. Calcium carbonate, calcium sulphate and tricalcium phosphate served equally well as sources of calcium. Later, Buckner, Martin and Peter (42) showed that the calcium in rock phosphate could be utilized for bone formation. In other publications, (Buckner, Martin and Insko, 38) they confirmed these results using limestone, raw bone meal, rock phosphate and dicalcium phosphate. Deobald, Elvehjem, Hart and Halpin (86) also found that the bone ash content was higher when the supplement contained phosphorus in conjunction with calcium. Although growth differences occurred, the calcium in limestone, gypsum, rock phosphate, calcium gluconate, "dicapho", steamed bone meal, and dolomite was equally available in spite of differences in solubilities of these supplements. When the vitamin D intake was borderline, the soluble salt calcium lactate, gave better growth and bone formation than the insoluble calcium silicate, whereas with adequate D no difference was apparent. When extremely insoluble calcium silicates were fed their availability was proportional to their solubility in dilute acids, increased amounts of the antirachitic vitamin having no influence. Using a rachitogenic diet, Higgins and Sheard (162) concluded that better growth and development took place in chicks fed tricalcium phosphate than in those fed dicalcium phosphate.

Buckner, Martin and Peter (49) concluded that limestone or oyster shell serve equally as well as sources of calcium for laying hens but the calcium in rock phosphate (tricalcium phosphate) could be utilized for growth of bone but not for egg shell formation. Fluorine was probably a factor in this result. Hunter, Dutcher and Knandel (181) found that calcium carbonate and calcium gluconate function with equal efficiency as sources of calcium for the growing chick, but for the laying hen the calcium gluconate was slightly more efficient. Kistler (211) observed that bone was superior to acid phosphate or raw rock phosphate in the production of eggs.

Buckner, Martin and Peter (49) compared calcium lactate, chloride, sulphate, and tricalcium phosphate with calcium carbonate, concluding that the calcium carbonate is more effective in egg production as judged by the weight of the egg contents and shell. Calcium chloride was not well tolerated. On the other hand, Fangauf and Kallman (105) obtained good results with this salt. Russell and McDonald (332) found that the laying bird can utilize the calcium from calcium citrate as well as from the carbonate for egg formation. Massengale and Platt (256) reported that birds receiving c.p. calcium carbonate as a source of calcium did not grow as well or lay as many eggs and produced eggs with less shell than those receiving oyster shell or limestone. Calcium carbonate in the form of oyster shell or limestone was better utilized than tricalcium phosphate, but the latter was superior to c.p. calcium carbonate. Limestone was somewhat superior to oyster shell. Buckner, Insko and Martin (41) concluded that marls served as satisfactory sources of calcium for laying hens.

Waite (391) found no difference in the utilization of the calcium from limestone and oyster shell for egg shell formation. Dougherty and Grossman (88) compared limestone with oyster shell and limestone combined, and found that the production was superior in the group receiving limestone alone, although the egg shells were equally good in both groups. Oyster shell was found by Kennard (205) to be superior to limestone, while Hart, Steenbock and Morrison (144, 145) recorded better egg production with oyster shell than with limestone, clam shell, dry bone, or quartz. Iowa workers (190) reported, from a comparison of oyster shell, clam shell and limestone, that the clam shell was inferior to the other two; similar results were obtained by Hart and Halpin (141), whereas Fangauf and Bruninghaus (104) could find no advantage in replacing cheap mussel shell with oyster shell.

Alder (4) compared oyster shell, blue limestone, dolomite, oolite and calcite, and found dolomite decidedly inferior because of its high magnesium content, with little or no difference between the other minerals. Tully and Franke (378) found no significant difference as judged by egg production, egg weight, and shell breaking strength between oyster shell, Black Hills limestone, dolomitic limestone, Meno chalkstone, clam shell, commercial limestone and commercial calcite. Martin and Insko (252) concluded that white shiny limestone was more attractive to birds than dull grey limestone, yet both were adequate sources of calcium for egg shell formation. Halpin and Lamb (133) reported that high levels of raw rock phosphate and phosphatic limestone were detrimental. Miller and Bearse (272) reported no appreciable differences in egg production, shell quality, egg weight, mortality, body weight and hatchability between lots of birds fed eastern oyster shell (Atlantic), clam shell, western oyster shell (Pacific), western limestone (Washington) and aragonite as sources of calcium. Egg production was significantly lower in the lot fed phosphatic limestone but in other respects it was the equal of the other lots. Since this supplement contained 1.3% magnesium, it is debatable whether its detrimental effect was due to this element or to fluorine. In one lot fed dicalcium phosphate in place of bone meal, along with eastern oyster shell, the production was lower. Guisti (122), Kitto (211a), Voelcker (390a), and Edin and Anderson (95) have also studied this problem.

From a consideration of the above reports, it would seem evident that the various commonly used sources for calcium and phosphorus supplements can be considered to be of equal value both for bone formation and egg production, with the exception of rock phosphate and phosphatic limestones which may be contaminated with fluorine, and of dolomite limestones on account of the magnesium content.

(i) Anticalcifying Properties of Cereals

King and Hall (210) concluded that the addition of oat groats (oats with the hulls removed) induced a more severe rachitic condition in chicks. Prolonged boiling of the groats with hydrochloric acid, without subsequent dialysis, appeared to render the anticalcifying substance more available. Vitamin D tended to overcome this effect. Unpublished data from the reviewer's laboratory, of a study involving corn, wheat, oats, oat groats and barley with graded levels of irradiated ergosterol, failed to show this anticalcifying property of oats. No cereal could be singled out as possessing this property in excess of the others. Lachat and Palmer (225) repeated the experiments of Hall and King but were unable to show that oat groats was more rachitogenic than yellow corn. However, using the A.O.A.C. diet they showed that oats and corn are rachitogenic, the former appearing to be more rachitogenic when the rations are otherwise only mildly rickets producing.

4. PEROSIS

Perosis, also known as slipped tendon, deforming leg weakness and hock disease, is a leg abnormality of young growing chicks. Since there has been some confusion in regard to the symptoms, a brief description, taken chiefly from Milby (269) is given. The joint which is affected, commonly called the hock joint, is the tibiometatarsal joint. Some workers incorrectly refer to this as the tibia tarsal joint—strictly speaking, it is the tibio-tarso-metatarsal joint. Bradley (27) describes the bones concerned as follows: "The distal end (of the tibia) has two articular elevations separated by a smooth groove. Strictly speaking, this part of the tibia represents the proximal row of the tarsal bones and the whole bone should therefore be called the tibio-tarsus. In the adult there is no independent tarsus. In the embryo there are indications of two rows of elements, but before long the proximal row fuses with the tibia and the distal with the metatarsus. The adult metatarsus, or tarsometatarsus is represented by one long bone composed of second, third and fourth metatarsal bones in union." In the normal chick the tendons at this joint glide between two lateral condyles on the distal end of the tibia, which is perfectly straight. In chicks afflicted with perosis, the first observable symptom is usually a slight puffiness about the joint. At this time the tibia is usually straight but the metatarsus may or may not be slightly bowed. In many cases, between the ages of 2 to 10 weeks, generally between 4 and 6 weeks, the tendons, particularly the gastrocnemius or Achilles tendon, slip from the condyles to one side or the other, and one or both legs may be affected. In other cases, the hock becomes flattened laterally and the legs are bowed but the tendons do not slip. Frequently the articular cartilage at the distal end of the tibia appears to be slipped slightly from its normal position.

Often the chick is unable to stand but rests on its hocks with the afflicted leg extended to the front or side. The bones of the legs, particularly the tibia and metatarsus become deformed to a greater or less extent, dependent upon the severity of the condition. The epiphysis at the distal end of the tibia is bent laterally in the direction in which the tendon slips. Milby (269) concluded that this bending was the result, rather than the cause, of the displacement of the tendon. However, Titus (371) claimed that at twelve weeks of age, when union of the epiphyses and diaphyses of the tibiae of normal chicks begins, these are ununited in chicks with perosis, a conclusion contrary to that of Hall and King (124).

This condition was differentiated from rickets by Hogan, Shrewsbury and Kempster (165), although a condition described by Mitchell, Card and Carman (275) and by Mussehl, Blish and Ackerson (289) was probably this deformity. It has been clearly demonstrated by numerous workers that vitamin D has no relationship to perosis, but in the earlier work on rickets in chicks perosis may have been a complicating factor. Battery brooders tend to aggravate the condition, although they are not primarily responsible, and the heavier breeds of chicks seem to be more susceptible than the light breeds. The reviewer saw this abnormality among chicks from the same hatch in the same battery room and fed the same ration in which almost every Jersey Black Giant chick and about one-half of the Barred Plymouth Rock chicks were afflicted, but White Leghorn chicks showed little or no evidence of the condition. As will be pointed out, the blood and bone analyses of perotic chicks are normal. Excessive amounts of minerals, particularly phosphorus, are associated with the condition.

Payne, Hughes and Leinhardt (308) could find no correlation between the inorganic calcium and phosphorus in the blood nor in the ash, magnesium, calcium nor phosphorus content of bone and perosis. A histopathological study of the organs and tissues revealed no abnormalities, so they concluded that the condition was of an anatomical rather than a histological nature. Hall and King (124) found normal serum calcium, and inorganic phosphorus, bone ash and bone phosphatase values. Holmes, Pigott and Moore (174) were unable to reveal any significant difference between the size and mineral content of tibiae from slipped-tendon chicks and those of normal chicks. They concluded that slipped tendons were not primarily due to faulty mineral metabolism—it is presumed that by faulty mineral metabolism, the authors referred to abnormal calcification of the leg bones. Similar findings were reported by Wilcke (402), Milby (267, 269, 270), Heller and Penquite (156), Herner and Robinson (160), and also in the reviewer's laboratory.

Hunter and Funk (182) reported a high incidence of slipped tendon among chicks fed diets containing relatively large amounts of meat meal, meat and bone meal, or bone meal. Later, Hunter, Dutcher and Knandel (180) produced the abnormality by the addition to the ration of such materials as bone meal, sodium phosphate, calcium carbonate, and mineral mixtures. Decreased amounts of these minerals lessened the trouble. They made a very pertinent observation: "the presence of protein concentrates rich in inorganic salts, aggravates the condition when salts or salt mixtures are fed at the same time". Card (57) also warned against excessive mineral feeding. Payne, Hughes and Leinhardt (308) found that a

mineral mixture of c.p. calcium phosphate and calcium carbonate produced the same deleterious effects as equivalent amounts of bone meal and concluded that an important etiological factor was an excessive amount of either phosphorus or calcium or both. Titus (371) using a ration containing 1.42% calcium and 0.92% phosphorus (with a total ash content of 5.7%) was able to produce perosis in 42.5 to 85.0% of the chicks to which it was fed. Perosis-producing diets have also been developed by numerous workers including Sherwood and Couch (349), Heller and Penquite (154), and a "synthetic" diet by Clifcorn, Elvehjem and Hart (65).

Herner and Robinson (160), Hunter, Dutcher and Knandel (180), Schaible, Moore and Conolly (337), Parkhurst and McMurray (305), Roberts (327) and Solun and Arsenjaw (356) as well as others previously mentioned, concluded that the etiological factor involved in perosis was excessive mineral feeding. Milby (268) reported from a statistical analysis that the level of calcium in the ration was not significantly correlated with perosis but the amount of phosphorus was positively correlated. However, he cautiously pointed out that these findings "do not justify the conclusion that phosphorus is the chief causative factor of slipped tendon, but merely indicate that high percentages of slipped tendon are associated with high phosphorus in the ration. This warning was probably caused by his earlier finding (267) that, although the amount of phosphorus in the ration was highly correlated with the percentage of slipped tendon, the number of slipped tendons which were produced by various levels of inorganic phosphorus was much less than would be expected on the basis of the phosphorus content of the ration. Later, Milby (269) again stated "the incidence of slipped tendon increased as the phosphorus increased. Though the trend was very definite, the relation between the amount of phosphorus in the ration and the percentage of slipped tendon was not exactly linear, indicating that factors other than the amount of phosphorus in the ration may have been operating to influence the incidence of slipped tendon." Incidentally, he encountered perosis in 24% of chicks fed on a ration containing only 0.43% phosphorus. McGowan and Emslie (264) believed that the preventive action of certain feeds was due to their content of organic or "delayed action" type of phosphorus. Insko, Sowell and Lyons (189) reported that a widening of the Ca : P ratio, with its accompanying increase of calcium in the ration from 0.4 to 3.1 : 1 did not increase the percentage of slipped tendon. Increasing the phosphorus content of the ration, by the use of bone meal, raised the incidence of perosis, although the Ca : P ratio was approximately the same. They concluded that the amount of phosphorus fed might be one of the causative factors. Hammond (136) found a high correlation between perosis and total phosphorus in the ration, and a negative correlation between organic phosphorus or calcium and perosis. He concluded that inorganic phosphorus in the ration was the primary factor. Milne (274) also associated a high phosphorus level in the ration with a high incidence of perosis. However she pointed out that the form in which the phosphorus is present may be the determining factor, since the substitution of meat meal and fish meal for milk caused a marked increase in perosis. Unpublished results from the reviewer's laboratory indicate that the mineral in meat meal is more productive of perosis than a similar amount furnished by fish meal. Maw (260) also concluded that bone char has some property which causes a reduction of slipped tendons

when compared with a similar amount of bone meal in the ration. Similarly when meat meal was replaced by fish meal the number of slipped tendons was reduced. Wilgus, Norris and Heuser (407) reported that the severity of perosis was as great when the calcium and phosphorus content of the diet was increased to 1.5% and 1.0% respectively by the use of steamed bone meal, as when higher levels were fed. C. p. calcium carbonate, hydroxide and chloride as well as c.p. mono-, di- and tricalcium phosphate increased the severity to about the same extent as bone meal, although in their earlier paper (405) they reported that c. p. monosodium phosphate produced more severe perosis than steamed bone meal or technical tricalcium phosphate. A technical grade of mono-calcium phosphate was preventive apparently due to some inorganic contaminating material.

A preventive factor in wheat bran and middlings was reported by Lee (232), while Hunter, Dutcher and Knandel (180, 183) found that oats or oat feed (hulls, shorts and germ) and oat hulls were protective. Titus and Ginn (373) and Titus (371) reported that rice bran was preventive. This was confirmed by Milby (269). Branion (28, 29) reported that corn contained a factor which produced slipped tendons, a finding confirmed by Schaible (335) and Wilcke (417, 418), while wheat germ, oats, oat dust (shorts and germ) and oat feed were preventive. Sherwood and Couch (348, 349) concluded that even in rations having a satisfactory mineral balance, another factor is necessary in the ration if slipped tendons are to be prevented. This factor was present in wheat gray shorts and in rice bran in appreciable amounts; oat groats, cottonseed meal and peanut screenings contained lesser amounts. Henderson (158) found that egg yolk or chicken fat did not prevent the abnormality. Graham, Pettit, Sykes and Howell (119) attempted to extract the preventive factor from wheat germ. Schaible, Moore and Conolly (337) claimed that soyabean oil meal was preventive. Wilgus, Norris and Heuser (405) rated the perosis preventing properties of some feeds as wheat germ 100, wheat standard middlings 65, red dog flour 50, wheat bran 40, ground oats 30, wheat 5, and soyabean oil meal 0. Yellow corn and dehydrated alfalfa meal had a slight preventive action.

Sherwood and Couch (349) confirmed the preventive action of wheat gray shorts but found that rations containing 1.90 to 1.93% calcium and 0.87 to 0.99% phosphorus, even though containing 30% of this material, produced more slipped tendons than did rations containing 1.20 to 1.62% calcium and 0.56 to 0.57% phosphorus. Wilcke (402) reported that 10 to 20% of corn bran, 10% of ground oats, and 5% yeast were ineffective, whereas 10% of rice bran or 20% of oats prevented the condition.

Finally Sherwood and Fraps (350) announced that the factor in wheat gray shorts which prevented slipped tendons was not an organic substance but was one or more of the mineral constituents of the ash. Wilgus, Norris and Heuser (406) as a result of their findings with monocalcium phosphate almost simultaneously reported that perosis could be prevented by either 0.0035 or 0.0160% of manganese in the diet, and the perosis-preventing properties of feed stuffs were roughly related to their manganese content. A mixture containing 0.0025% each of manganese, aluminium and iron was preventive at lower calcium and phosphorus levels, while aluminium and zinc had a less effective action. Further results with

manganese were reported by Gallup and Norris (114, 115), indicating that manganese did not prevent all cases of perosis under certain conditions. Van der Hoorn, Branion and Graham (387) using purified diets encountered a leg abnormality, presumably a mild type of perosis, which was prevented by manganese. Milne (274) found silicon to be without influence. Heller and Penquite (156) found a water extract of rice bran to be preventive, although water extracts of wheat bran, wheat gray shorts, wheat embryo or alfalfa were not very effective. The ash of rice bran was preventive and the ash of wheat germ slightly so, although in an earlier paper (154) they found the ash of rice bran to be ineffective. They observed a correlation between the manganese content of the ration and perosis-preventing property, so they concluded that it may be the deficient factor. However since some of the best protective rations had no manganese addition, they concluded that other factors were involved. Miller and Bearse (419) encountered perosis on corn and barley diets but not in birds fed oats or wheat. The manganese content of the grains was oats 4.66 mgms. per 100 grams, wheat 2.91, barley 1.19, and corn 0.38 mgms.

Lyons, Insko and Martin (238) confirmed that protective action of manganese, but noted no protective action of aluminium nor zinc, rather the reverse, Since the mode of action of manganese in preventing perosis was not known, they eliminated its action in the digestive tract by an ingenious experiment, involving intraperitoneal injections. Such injections of the proper amounts of manganese were effective in preventing perosis, whereas zinc, aluminium or iron were valueless. Schaible, Bandemer and Davidson (336) found a wide variation in the manganese content of feeding stuffs and even a variation in the same feed from different sources. They confirmed the perosis-preventive action of manganese, but concluded that all sources of manganese, using various salts and ores, were not equally satisfactory.

Wiese, Elvehjem, Hart and Halpin (401) found that, although 10% of rice bran prevented slipped tendons, alcohol, glycerol or acid extracts of rice bran did not. Since autoclaving the bran destroyed a factor which prevented perosis, they concluded that there was some labile substance which either alone or in association with manganese was operative in preventing perosis on the particular ration used. The addition of 0.0025 and 0.005% of manganese to their simplified ration protected, whereas with another ration, containing higher levels of calcium and phosphorus, neither 15% of rice bran nor the addition of manganese was effective. They also observed some interesting difference in total blood phosphorus on these various diets. Schaible, Bandemer and Moore (336a) have studied some physico-chemical effects of excess minerals in the gut.

It is obvious from this mass of evidence that the perosis picture is not complete. It seems safe to conclude that excessive minerals, particularly phosphorus, are an etiological factor, although one cannot be positive, even in this regard, since the level of phosphorus in the ration and the incidence and severity of perosis do not go hand in hand. It seems obvious that manganese is *a* protective mineral, but it is also obvious that Mn *is not* the *only* protective factor involved. In view of the variation in the manganese content of feeding stuffs, the minute quantity required, and the fact, which will be considered later, that excess manganese is

harmful, it does not seem advisable nor sound practice to advocate, as has been done, the addition of this mineral to commercial poultry rations. If perosis develops on a ration, the addition of manganese to that particular ration, under the particular environmental conditions may be justified. Since the *modus operandi* of this mineral is not yet clear, its use under such conditions may not give the desired results.

Moreover, it seems evident that a histological study of the tibio-metatarsal joint and its attendant ligaments may be necessary to ensure that the various rations used by experimenters result in one and the same perosis.

5. POTASSIUM, SODIUM AND CHLORINE (SALT)

The alkali metals, sodium and potassium, are found normally throughout the body in the soft tissues and body fluids. Although they are closely related, their unequal distribution suggests selective separation and characteristic functions. Sodium, chiefly as chlorides, carbonates and phosphates, predominates in the blood and body fluids, whereas potassium occurs, chiefly as phosphates, to a greater extent in the cells, soft tissues and muscles. Although a deficiency of either sodium or potassium retards growth, their functions in the body are not clear. Potassium seems to be essential for proper cell formation. The ions of sodium, potassium and calcium, in proper balance, are concerned in the rythmical activity of the cell and are essential for heart activity. These alkali minerals are intimately connected with the regulation of the hydrogen ion concentration of the blood. Sodium chloride (salt) is the chief inorganic constituent of blood plasma, and presumably is the source of the chloride ion in the hydrochloric acid of the gastric juice. Salt metabolism is related to water balance and there is a relationship between sodium requirements and the adrenal glands.

Potassium, sodium and chlorine are excreted by the kidneys. Potassium is especially abundant in both plant and animal tissues, so no naturally occurring deficiency of this mineral should ever arise. On the other hand, farm rations, in general, particularly those consisting largely of cereals, do not contain sufficient amounts of sodium nor chlorine. Hence the need for common salt as a mineral supplement for livestock has been widely recognized. It is generally accepted that poultry rations should contain from 0.5 to 1.0% salt. However, such products as meat meal, fish meal and dried milk contain appreciable quantities of salt, and with poultry rations containing the usual amounts of these supplements, it is doubtful if 0.5% salt is required. However that amount does not appear to be harmful, under such conditions, and it is probably a safeguard, for a considerable variation in the salt content of feedstuffs does occur.

Mitchell and Carman (279) showed that chicks fed on a cereal diet, which was deficient in salt, evidenced retarded growth, with a decreased efficiency of food utilization, which was not due to a failure in digestibility. They concluded that a deficiency of sodium rather than of chlorine was involved. Prentice (322) reported that chicks fed on rations containing no salt made poor growth, with inefficient food utilization, marked susceptibility to disease and retarded sexual maturity. He also concluded that the beneficial effects of sodium chloride were due to sodium rather

than chlorine since sodium bicarbonate gave similar results while glycine hydrochloride was without effect. He recommended that a chick mash should contain 0.5% salt. Prentice suggested that grass plays an important part in balancing a ration deficient in sodium. Later, the same worker (323) showed that a lack of salt in the ration fed to laying hens resulted in a decreased rate of egg production and egg size, the birds losing weight and becoming subject to cannibalism. Mitchell and McClure (280) estimated that one egg contains 73 mgms. of sodium and 88 mgms. of chlorine, amounts furnished by 186 mgms. of salt. Common (71) has reported that calcium retention of laying birds is adversely affected by a lack of salt, probably sodium deficiency.

In the reviewer's laboratory, chicks could be successfully reared on a simplified diet, normally containing 4% of McCollum salt mixture 185, in which 2% of this mineral mixture was replaced by 2% of grass ash, or on diets in which the mineral mixture was entirely replaced by 3 5% grass ash and 0 5% salt. Complete substitution of grass ash for the salt mixture resulted in little growth, indicating that grass is deficient in either sodium or chlorine or both.

Some poultrymen consider that the use of salt increases the palatability of the ration, but Payne (307) could not confirm this.

Excessive amounts of salt are toxic to chickens. Collier (69) was able to feed 0 042 ounce per hen per day without any symptoms, but 0 063 ounce caused diarrhoea. He concluded that 1 ounce of salt per day could be fed safely to 100 mature birds. Wheeler (398) stated that a safe level was 5 ounces of salt to every 100 pounds of feed. Suffran (363) reported a case in which fowls were poisoned by being fed a mash made of potatoes to which salt had been added, chemical analysis showing that each bird had ingested 10 to 14 grams of salt. From subsequent experiments he concluded that a dose of 4 grams per kilogram body weight was lethal. Edwards (97) also reported a case in which fowls and ducks were killed by being fed the sweepings, containing about 22% salt, from a bakery. Using pigeons, he determined the minimum lethal dose as 3 33 to 4 50 grams of salt per kilo body weight. The symptoms noted by these workers were inability to stand, intense thirst and convulsions, with a viscous discharge from the beak. Post mortem examination showed hemorrhages and congestion in the gastro-intestinal tract. Other workers have reported lesions in many organs, particularly the kidneys. Heinz and Haas (150) also encountered salt poisoning among birds eating heavily salted garbage. Pearl, Surface and Curtis (311) reported a serious case of salt poisoning.

Mitchell, Card and Carman (275) found that chickens could be fed from 9 to 21 weeks of age, on rations containing as much as 8% of salt, with no detrimental effect on their condition, nor rate of growth, once the birds became accustomed to the ration. A daily intake of 6 to 8 grams exerted no harmful effects on birds 9 weeks or older. Salt given in solution twice daily was more toxic than equal amounts consumed in the feed. The minimum lethal dosage for birds weighing from 3 to 5 pounds was 4 grams per kilogram body weight (*i.e.* 0.4% of the body weight). Parker (303) arrived at a similar conclusion. Quigley and Waite (326) fed baby chicks on rations containing from 1 to 15% salt; 8% or greater levels resulted in less growth due to the unpalatability of the ration. They also

determined the minimum lethal single dose to be 4 grams per kilo body weight, although a larger dose could be tolerated if divided.

Torrey and Graham (375) reported that ducks are more susceptible to salt poisoning than chickens.

Sjollema (352) fed chicks on rations containing only 0.034 to 0.013% sodium, and obtained poor growth and food utilization in comparison to those receiving 0.5 and 1.0% salt. He found that 2% salt (0.8% sodium) in the ration was injurious. The sodium requirements of chicks were estimated as 0.4 to 0.5% at 1 month of age and at 0.30 to 0.35% at 2 months. Halpin, Holmes and Hart (131) reported that rations containing 1% salt resulted in somewhat better growth, when fed to baby chicks, than rations with no salt addition, and very much better growth than with rations containing 5% salt. In a later experiment (132) using baby chicks and pullets they concluded that 5% of salt was more than was desirable, that 2% of salt was not injurious, neither was it advantageous, obtaining satisfactory results with 1%.

Heller (151) reported that naturally alkaline and saline waters were injurious to chicks, but an adjustment to these drinking waters could be achieved, though at the expense of egg production. Selenium may have been partially responsible for the injurious effects.

Some poultrymen recommend the use of a "soda flush" (sodium bicarbonate) for chicks. Delaphane (83) and Witter (410) have shown that this is not a safe practice, since excess amounts or continued administration results in kidney damage.

6. IODINE

The hormone or regulatory agent secreted by the thyroid, two separate lobes laterally situated at the base of the neck, is known as thyroxin. It is a derivative of tyrosine, containing about 60% iodine. Most of the iodine in the body is found in the thyroid since it has a special affinity for iodine. The lobes are filled with a colloid material containing iodine in an organic combination with globulin, known as thyroglobulin. It is probable that thyroxin exists in the gland as thyroglobulin and that other iodine compounds may be present in the gland.

Iodine comes from the sea, and the soil and plants of inland regions are deficient in this mineral. In such areas simple, endemic, or colloid, and in some instances congenital goitre, an enlargement of the gland due to increase in the colloid material, arises as a result of this lack of iodine. The Great Lakes region of North America and part of the Prairie Provinces of Canada are such regions. The administration of iodine alleviates the condition.

Welch (396) in Montana, reported that "goitre in poultry is very common." "Flocks with a very high percentage of it have been noted in goiterous areas. The enlarged thyroid, frequently as large as the thumb, is entirely concealed by the feathers, and so far we have not observed any bad effect on the health of these fowls. The owners of goitered flocks have always reported that egg production and general health were normal. We have attempted to determine whether congenital goitre existed among newly hatched chicks but have been unable to get the material to study. No losses have been reported, at any rate, from this cause." Kernhamp (208)

gave a detailed report of a simple colloid goitre in poultry, and mentioned that in Minnesota, goitre in poultry is extremely uncommon.

The weight of the thyroid per kilo of body weight and the percentage of iodine therein, is greater in poultry than in mammals, according to Chaudhuri (62) and Cruickshank (80, 81). A higher metabolic rate results as shown by body temperature of 104 to 108° F., with more rapid respiration, heart beat, digestion and absorption and greater food consumption per unit weight than mammals. In view of these circumstances, it might be considered that goitre would be a fairly common poultry disease. However the disease appears to be almost non-existant. Several factors are operating in this connection. Marine products such as fish meal, kelp, oyster shells and fish oils, which all contain appreciable quantities of iodine, are common ingredients in poultry feeds. Moreover the use of iodized salt (ordinary salt containing 0.02% or more of potassium iodide) is common. In this connection the voluminous literature dealing with the benefits or lack of beneficial effects from supplemental iodine feeding is contradictory. Many workers have added iodine, usually as potassium iodide, to a basal diet but either did not determine the amount of iodine in this diet, or neglected it. This basal may or may not have contained adequate amounts of iodine, without any further supplementing. Moreover, even a proven benefit of iodine feeding in a goitre area is no proof that in non-goitre regions iodine supplements will be beneficial.

Chaudhuri (62) and Cruickshank (80, 81) have shown that there is a relative increase in the iodine content of the thyroid with the attainment of sexual maturity. Cruickshank (80, 81) has also shown that the iodine content of the thyroid is affected by ingestion of food, age, species and season. Iodine administered either orally or injected is rapidly removed by the gland. Orr and Leitch (298) found that the thyroids of birds receiving 1 mg. of iodine daily for three weeks contained 0.3 to 0.5% iodine (fresh weight basis) as compared with 0.1 to 0.2% for the controls. Simpson and Strand (351) obtained similar results. The thyroid weight and total iodine increased in proportion to body weight in the growing chick. There is a seasonal variation in thyroid weight (from 0.085 gm. in March to July to 0.13 gm. from January to March) and a similar variation in percentage and total iodine. This was related to egg production since the greatest weight was previous to the period of maximum egg production and the iodine content is depleted somewhat after a period of heavy egg production, as confirmed by MacOwan (266). Ovarian tissue contained only a trace of iodine, the small ova very small amounts, and the mature yolks appreciable quantities. Cruickshank (81) reported that Latimer of Minnesota (a goitre area) gave the average weight of the thyroid as 0.173 gm., as compared with 0.13 gm. obtained in England with the same breed, at the same period of the year. She concluded from a histological study that the thyroid was in relatively great activity in the immature bird and inactive in the laying and moulting hen.

That the thyroid gland is concerned in moulting and feather development is evident from the work of Cole and Reid (68), Crew and Huxley (79), Giacommi (117), Hutt (184, 185), Krizenecky (217, 218), Torrey and Horning (376, 377), Zavadovsky (412, 413), Cole and Hutt (67), and Prawochenski and Slizynski (321).

Hamilton and Kick (135) were unable to obtain any beneficial effects by the addition of iodine to a basal mash fed to young chickens. Similar findings were reported by Forbes, Karns, Bechdel, Williams, Keith, Callenbach and Murphy (108), and Holmes, Pigott and Packard (175). Conflicting results have also been obtained as to the value of iodine administration to laying birds, probably as has been pointed out, the amount of iodine in the control ration being the determinant factor. Negative findings have been reported by Forbes *et al.* (108) who could find no definite effect of the iodine on egg production. Similarly Malan (240) found that hens receiving an iodine supplement to a ration not considered to be deficient in iodine, showed no advantage in mortality, egg production or fertility. Wehner (395) reported that feeding 0.5 gm. iodine daily had no effect on the course of the moult, general health, egg production or hatchability. Similarly Johnson, Pilkey and Edson (194), although in a goitre area, found that supplementary iodine feeding did not improve egg production, fertility, hatchability, or mortality; and Lee, Hamilton and Henry (233) could demonstrate no improvement in egg production or mortality as a result of feeding either inorganic or organic iodine as a supplement to a laying mash containing 715 parts per billion of iodine originally. Almquist and Givens (5) have found no significant difference in egg production or hatchability. Kelly (204) reported that in one trial, egg size was increased by the addition of iodine to the diet of the hen, in another the reverse was true, while a third trial gave inconsistent results. Edson (96) found that the addition of iodine to a ration containing 19 to 41 parts per billion gave no improvement in egg size, percentage of thick albumen, yolk index, weight or colour, or shell thickness.

On the other hand, Simpson and Strand (351) increased the egg production of old hens, who also appeared healthier with more rapid moulting and recovery. Similar conclusions were made by Klein (213), Scharrer and Schropp (333), and Zaitschek (or Zajtay) (411). These latter workers also reported increased hatchability. Crew (78) reported that senile females were markedly stimulated to egg production by large doses of thyroid, although Cole and Hutt (67) found that 59 mg. of dessicated thyroid per pound of live weight had no appreciable effect on egg production.

Mitchell and McClure (280) estimate the daily iodine requirement of a five pound chicken as 4.5 to 9.0 gamma (a gamma is 0.000001 of a gram, or 1 microgram), and Orr and Leitch (298) give the requirement of a 4-pound fowl as 5 gamma. The use of the usually recommended amounts of iodized salt would adequately meet these requirements. Although poultry can withstand considerable amounts of iodine, according to Orr, Crichton and Middleton (297), Schmidt (338), and Scharrer and Schropp (333), being more resistant than mammals, there is danger of overdosage with iodine. Schmidt (338) found that doses of 0.3 to 0.5 grams reduced the size of eggs, and 1.5 gm. interrupted the laying period. Decreased egg size was encountered by Peano and Pissaro (309). Brown (31) reported that hens refused to eat a mash containing 0.2% potassium iodide. Zavadovshii, Lipichina and Radsivon (414) and Hutt (185) showed that daily doses of 4 mg. thyroid iodine per 1 to 2 kilograms of body weight was lethal. Asmundson, Almquist and Klose (7) fed iodine in amounts varying from 800 to 16,000 gamma daily to hens fed on a ration containing 50 gamma

per 100 gm. Iodine was fed in various forms as oyster shell, dessicated thyroid, sodium iodide, potassium iodide, iodo-salicylic acid (which was not readily absorbed), di-iodotyrosine and iodized olive oil for 20 weeks. The iodine content of the eggs varied from 3 to 1730 gamma per egg, but body weight, egg production and feed consumption were not affected adversely, except in the case of those birds fed thyroid and those receiving the high dose of sodium iodide.

The percentage of iodine in the egg can be increased many times by the addition of either inorganic or organic iodine to the ration of the hen, as shown by Ambrosio (6a), Simpson and Strand (351), Jaschik and Kieselbach (192), Straub (361), Chrzaszcz (63), Peano and Pissaro (309), Zickgraf (415), Viollier and Iselin (390), and Sumita, Kawabata and Fujioko (364). Wilder, Bethke and Record (403) concluded that the iodine content of hens' eggs varies directly with the amount of this element in the ration, but Almquist and Givens (5) reported that the iodine content of eggs was not closely proportional to the iodine content of the ration. The iodine content of eggs has been measured by Cole, Curtis and Bone (66), while Vezzani, Devalle, Meynier and Simonetti-Guizza (389) have used iodized eggs successfully in the treatment of goitre. The bromine content of eggs can also be increased, Purjesz, Berkessy and Gonczi (324, 325), and Berkessy and Gonczi (12, 13).

In our laboratory, the results of a co-operative experiment with the Toronto Hospital for Sick Children, showed that the incorporating of an organic form of iodine in a rachitic diet did not lessen the vitamin D requirement of chicks nor did it increase the efficiency of irradiated ergosterol in promoting calcification.

Free iodine in the form of colloidal iodine has been employed as a disinfectant, Chandler (60).

7. IRON AND COPPER

Hemoglobin, the red colouring material in blood, consists of a protein globin and heme, as iron-containing pigment. This compound is responsible for most of the oxygen carrying capacity of blood. Iron is essential for the formation of hemoglobin; in its absence nutritional anaemia results. In addition to the iron in hemoglobin, which is the largest fraction, a smaller amount is present in muscles as myoglobin, some as tissue iron and reserves of varying level in the spleen, liver and kidney. Iron is probably present in every living cell and seems to be concerned in vital activities, particularly physiological oxidations, being a constituent of several respiratory enzymes such as cytochrome.

It seems to be generally agreed that iron to be absorbed must be soluble, ionisable and ultrafilterable. Reduced iron, ferric hydroxide and salts soluble in acid solutions meet these requirements. This mineral is almost wholly excreted by the intestine.

The utilization of iron in the rebuilding of hemoglobin (hematopoietic process) depends upon traces of copper. The addition of pure iron increases the iron content of the liver and spleen but only in the presence of copper is this stored iron used in the hematopoietic process. Commercial iron salts are usually contaminated with sufficient copper. Elvehjem, Hart

and Kemmerer (98) have shown that both iron and copper are required for hemoglobin synthesis in chicks.

The green leaves of young plants are rich in iron, and other feeds with a good iron content are meat products, legume seeds, cereal grains and cane molasses.

The hemoglobin level of chicks has been reported as between 6 and 7 gm. per 100 cc. by Hart, Elvehjem, Kemmerer and Halpin (140), and as 8.2 gm. for male and 7.5 for female chicks by Cook and Harmon (76). Holmes, Pigott and Campbell (172) followed the hemoglobin level of chicks from hatching to 21 days. The hemoglobin level at hatching was high, being 10.8 gms. per 100 cc. on the average, as would be expected from the results of Sendju (221) who found that the hemoglobin content of incubated eggs increased slowly to 22 mgs. at the fourteenth day and rapidly to 140 mgms. at 20 days. McFarlane and Milne (263) and Szejnman-Rozenberg (368) have investigated the iron and copper metabolism of the developing embryo. Copper metabolism has been studied by Loeschke (236a) and Sumegi (363a). Following hatching, the hemoglobin level falls, reaching a low level of 8.8 to 9.0 gms. at 5 to 7 days. This period of "physiological anaemia" lasts until about the seventeenth day of life, at which time, the hemoglobin level begins to increase, being 9.6 gms. per 100 cc. at 21 days. However Holmes, Pigott and Campbell (171) found a wide range in hemoglobin values for 21-day old chicks, though they were from a common source and fed on the same ration. On the other hand, Hart, Elvehjem, Kemmerer and Halpin (140) concluded that a practical baby chick ration supplies enough iron and copper to prevent anaemia.

There is no doubt that anaemia is a cause of embryonic mortality during incubation, under certain conditions. Smith and Branion (355) and Smith (353, 354) encountered anaemic embryos in eggs laid by hens fed certain diets, particularly those containing tankage. Direct summer sunshine and/or good grass range alleviated this mortality. McFarlane, Fulmer and Jukes (262) could not correlate this condition with the iron and copper content of the eggs. Cavers and Hutt (59) reported a similar condition, which was more frequent in the fall and winter months, very few anaemic embryos being found in March or April.

In the laying hen, the demand for iron and copper for egg formation is large, since the average egg contains about 1.1 mgm. of iron and 0.067 mgm. copper. Elvehjem, Kemmerer, Hart and Halpin (99) give the values for egg yolk as 0.0143% iron, and the amount of copper as 0.00076% in yolk and 0.00056% in egg white. They were unable to increase these values by feeding extra iron and copper to the hen. Similar results were reported by Hoffman (164) and by Erikson, Boyden, Martin and Insko (103), although they found that hens with access to sunshine and blue grass range produced eggs with higher iron and copper content. This finding is probably significant, since anaemic embryos also tend to disappear, under similar conditions. Vecchi (388) claimed that the iron content of eggs could be raised by adding iron to the hen's diet. Although McFarlane, Fulmer and Jukes (262) encountered significant variations in the iron content of egg yolk, they could not correlate these variations with the ration. The copper content of eggs was extremely variable.

The data available on the hemoglobin content of the blood of mature birds is variable, the reported normal values ranging from 7.0 to 11.1 mgms. hemoglobin per 100 cc. It should be noted that some workers report the iron content rather than hemoglobin content of the blood. Among others Burmester (52), Scott, Serfontein and Sieling (344), Hayden and Fish (149), Dukes and Schwartze (91) Gonzaga (118), and Dyer and Roe (94) have reported hemoglobin or iron values. Some of the variation is due to technique, Schultze and Elevhjem (342); some to differences in the age of the birds, Dukes, Schwartze and Brandt (92); to the season of the year, since these last workers have shown that the hemoglobin level is higher in winter; to individual variation, Maughan (258) and Cook and Harmon (76) and possibly to the rate of egg production. It seems quite definitely established that the blood of chickens has a lower hemoglobin content than that of man, Burnett (53), Klieneberger and Carl (214), Forkner (109) and Maughan (258), and that males have a higher hemoglobin content than females, with capons intermediate. Some of these variations may be due to the fact that the hen's spleen serves as a reservoir for red cells, thus helping to regulate the hemoglobin level in the blood, Harmon, Ogden and Cook (138). This splenic reserve was found by Harmon (137) in cockerels, capons, pullets and laying hens but not in cocks nor broody hens.

Some mineral supplements containing iron have been sold as supplements to laying mashes to prevent nutritional anaemia in the hen. However, the evidence is not unanimous that anaemia accompanies egg production. Dukes, Schwartze and Brandt (92) found no correlation between spring egg production and the hemoglobin content of the blood of the laying hens. Winter (409) also concluded that production, confinement or moult do not produce quickly noticeable or marked changes in the iron content of the blood, although earlier (408) he stated that egg production does cause a decrease in the hemoglobin level of the blood. Schultze, Elvehjem, Hart and Halpin (343) found that a practical laying ration furnishing about 14 mg. of iron and 0 5 mg. of copper per hen per day could support heavy egg production without a resultant lowering of the hemoglobin content of the blood. Feeding of additional iron and copper failed to raise either the hemoglobin level or egg production. On the other hand, Maughan (258) and Cook and Harmon (76) observed that the hemoglobin level fell with high egg production, the fall occurring previous to the onset of egg production, when the yolks are forming. Feeding of additional iron increased the hemoglobin level in one case, and was useless in the other. Harmon (137) reported that the hemoglobin level was high at hatching and at maturity, but low at two weeks of age. Egg production distinctly decreased the hemoglobin level, but high producers had higher levels than low producers, when both were either in or out of production. The hemoglobin level rose rapidly with the onset of broodiness.

From this contradictory evidence, one is faced with certain possibilities. A judicious balancing of the laying ration may adequately meet the increased requirements for iron and copper for egg production. If not, especially if iron supplements may not be effective, then it is possible that the hen withdraws iron from her body stores in preference to dietary iron for deposition in the egg. If paleness in the head and comb can be

considered as one indication of anaemia, then many poultrymen would suspect that anaemia does arise in flocks laying heavily during the winter months, particularly in view of the fact that the hemoglobin level of newly hatched chicks varies. That this is not due directly to confinement, would seem evident from the results of Winter (409) and Doyle, Matthews and Roberts (90). Moreover, anaemic embryos are more common during the winter months, and although it seems evident that iron supplements do not increase the iron content of the egg, three facts need consideration. First, grass and sunshine apparently do raise the iron content of the egg; second, grass and sunshine or sunshine alone, prevent anaemic embryos; third, laying hens allowed to range on a good "short grass" range soon "redden up." One is tempted to theorize that ultraviolet light has some influence on hemoglobin (cf., Maughan, 257) and that young grass contains iron that is abundantly available, be that due to the form of the iron, the combination in which it is present, or other mineral compounds also contained therein. Iron metabolism in poultry nutrition would seem to be a still fertile field for research.

Marza, Marza and Chiosa (253) have made a study of the distribution of iron in the ovary of the hen.

Although many texts accept egg yolk as one of the best foods for hemoglobin regeneration because of its high iron content, Whipple and Robscheit-Robins (400) have shown that it is relatively inert for hemoglobin production. Sherman, Elvehjem and Hart (346) reported similar findings, since incomplete hemoglobin regeneration resulted from feeding egg yolk as a source of iron, together with 0.05 mg. copper, although the α-α-dipyridine method showed the iron to be nearly 100% available. The addition of 1 mg. of supplemental copper to the egg yolk gave normal hemoglobin regeneration, indicating that the failure was due to retarded utilization of copper, probably as a result of the formation of insoluble copper sulphide in the digestive tract. Summerfeldt (365), pointing out that the solubility of iron depends upon the degree of acidity present in the gastro-intestinal tract, and also on protein digestion which liberates iron bound with protein, made use of an artificial gastric juice, which simulated normal conditions found in the stomach of children. The solubility of the iron in egg yolk under these conditions was only 21%.

Deobald and Elvehjem (85) reported that the addition of large amounts of soluble iron or aluminium salts (0.9% Fe, 0.44% Al) to a normal ration, resulted in severe rickets, due to the formation of insoluble phosphates during digestion. These results may account for the beneficial results reported for iron and aluminium salts on perosis. Some of the excess phosphorus in the diet would be rendered unavailable to the chick.

8. MANGANESE

The relationship of manganese to perosis has already been considered. However, it is becoming more evident that this element plays other rôles in poultry nutrition. It has been reported as being concerned in hemoglobin regeneration.

Van der Hoorn, Branion and Graham (387) showed that it was an essential mineral for poultry. Keenan, Kline, Elvehjem, Hart and Halpin (420) modified the salt mixture used in a purified diet for chicks so as to

contain 0.246 gm. manganese sulphate, 0.209 gm. zinc chloride and 0.225 gm. copper sulphate per kilo, but they gave no reasons for this modification. Gallup and Norris (115) found that about 50 parts of manganese per million parts of the ration were necessary for growth, a reduction to 10 p.p.m. resulting in retardation. Similar findings were reported by Schaible, Bandemer and Davidson (336). The former workers also reported that pullets fed on a ration containing 13 p.p.m. manganese produced less eggs, with lower hatchability, than those fed a diet with 200 p.p.m. Increasing the manganese content of the hens' ration increases the manganese content of the eggs according to Vecchi (388). Gallup and Norris (115), and Lyons and Insko (237) who were able to increase the manganese content of the eggs laid by hens receiving a ration with 5.5 p.p.m. from 0 43 to 0.56 p.p.m. (dry matter) to 0.84 to 0 96 p.p.m. with 45.5 p.p.m. in the diet. Peterson and Skinner (312) gave the manganese content of egg yolk as 2.3 and McHargue (265) as 1 5 p p.m. Bertrand and Medigreceanu (17) gave the content of the edible portion (yolk and albumin) as 2.52 and Peterson and Skinner (312) as 1.1 parts per million. Schaible, Bandemer and Davidson (336) gave the manganese content (mg. per kilogram) of some feedstuffs as follows: corn 4 1 to 7 8, wheat 24 to 37, wheat germ 155 to 167, oats 31 to 44, oat hulls 275, rice 19, barley 12 to 18, meat meal 4 to 5 and fish meal 16 to 93. They also investigated the availability of the mineral in the form of various salts, such as sulphate, dioxide, permanganate, carbonate, and ores such as rhodonite and rhodochrosite. All were not equally satisfactory.

One of the most interesting discoveries was that of Lyons and Insko (237) that hens fed on a low-manganese ration had low hatchability, with a high percentage of chondrodystrophic embryos. Supplementing the ration with manganese, iron and zinc resulted in good hatchability, even the embryos which died having normal skeletons. Chondrodystrophic embryos contained an average of 2 4 micrograms of manganese while those embryos with normal skeletal development contained 7 0 micrograms. That manganese was the element concerned was shown by injecting manganese directly into the egg, which prevented the abnormality. Zinc was ineffective.

This discovery is so interesting that it warrants further discussion. Chondrodystrophic embryos are characterized by "very short, thickened legs, short wings, parrot beak, globular contour of head, protruding abdomen and retarded down and body growth." Oedema is often present. This abnormality was first reported by Landauer and Dunn (227). Hutt and Greenwood (187) found that its frequency was high in January but declined steadily to a complete absence in June. Munro (283) also observed this seasonal incidence. Byerly, Titus, Ellis (55) concluded that vegetable proteins in the diet of the hen increased its incidence, but they did not observe any seasonal variation, nor did Upp (383). Later, Byerly, Titus and Ellis (56) reported a different type of chondrodystrophy which could be prevented by wheat germ and liver or wheat germ and whey in the ration or by allowing the hens access to direct sunlight and green grass. The findings of Smith (353, 354) and Smith and Branion (355) would confirm this. Landauer (226) differentiated between two types of this abnormality—sporadic and nutritional; the former has a peak of mortality

during the second week of incubation, the latter during the last few days. The sporadic type have bent tibiae, whereas the tibiae of the nutritional type are reasonably straight. Green grass presumably is a good source of manganese, as is wheat germ, and their preventive action could be thus explained. The rôle of sunshine is not clear.

It should be pointed out again, that van der Hoorn, Branion and Graham (387), Heller and Penquite (156) and Gallup and Norris (115) have shown that excess manganese is detrimental.

Manganese is eliminated in the faeces and urine.

Although the reviewer does not feel, as has been pointed out, that sufficient information is available to justify the addition of manganese to all poultry rations, nevertheless there undoubtedly will be some individuals who will desire to make such additions. Fifty parts per million of manganese would seem to be about the correct amount in the rations. One-quarter of a pound of a technical grade of manganese sulphate (containing 32 to 33% manganese) per ton of mash will raise the content well above the marginal level. It will be necessary to pre-mix this amount with some other ingredient in order to obtain uniform distribution in the completed mash.

9. MAGNESIUM

Magnesium is closely related to calcium metabolism. It is essential for certain body activities, being present in muscle tissues where it acts as a co-enzyme for the breakdown of adenylphosphate during muscle contraction. It is also a co-enzyme for phosphatase. About two-thirds of the magnesium is present in the skeleton, chiefly as carbonate, egg shell containing about 1.4%. It is excreted to some extent in the faeces and in the urine. In considering magnesium the distinction between food magnesium and blood magnesium is striking, since several disorders are characterized by hypomagnesaemia but not by magnesium deficiency in the ration.

As has been pointed out, dolomitic limestone often contains a sufficient percentage of magnesium carbonate to be harmful when used as a mineral supplement. Wheeler (399) showed that rations deficient in calcium but carrying abundant magnesium produced a shortage of calcium and mineral in the bones of chickens. He also showed that magnesium would not substitute for calcium in egg shell formation. Halpin and Hayes (130) reported greater egg production with oyster shell than with limestone which contained a relatively high percentage of magnesium. Buckner, Martin and Insko (40) found that the addition of magnesium carbonate to chick rations, in amounts sufficient to bring the magnesium level from 0.76 to 7.05%, disturbed the calcium and phosphorus balance, resulting in deformed bones with a low ash and calcium content. They also reported that in the earlier work at the Kentucky station they used limestones containing from 1 to 30% magnesium carbonate. Best results in bone formation and egg production were obtained when the percentage of magnesium carbonate in the limestone was small. A decrease in bone ash as a result of feeding 3% magnesium carbonate (0.89% Mg) was encountered by Milby (268, 269) although growth was normal. Mussehl, Hill, Blish, and Ackerson (291) reported similar results and Schaible, Moore and

Conolly (337) obtained perosis with magnesium carbonate additions. Miller and Bearse (272) encountered difficulties with a phosphatic limestone, analysing 1.3% magnesium. Fluorine may also have been involved. Alder (4) found dolomite to be injurious. On the other hand Hart, Steenbock and Morrison (145) claimed that the addition of 4 or 5% of limestone containing as much as 40% magnesium carbonate promoted normal growth and reproduction in chickens.

However, it would seem safer to avoid the use of dolomite limestones in poultry rations. Suitable limestones should contain about 98% calcium carbonate.

Magnesium may be concerned in egg production, since Charles and Hogben (61) found the level of serum Mg to be as 2.08 to 2.71 mg. per 100 cc. in immature pullets, 1.87 to 2.87 mg. in laying pullets with no egg in the oviduct, and as 1.86 to 5.90 mg. with the egg in various stages of shell formation.

10. FLUORINE

Although fluorine is widely distributed in soils, rocks, waters and in plant and animal materials, it apparently has no function to perform in metabolism, in fact there is ample evidence that this element has detrimental physiological effects. However, because of its widespread distribution, and particularly because of its occurrence in rock phosphate and phosphatic limestone sometimes used in mineral supplements, fluorine requires consideration in this review.

Drinking water containing less than 1 p.p.m. of fluorine appears to be harmless, that containing 1 to 2 p.p.m. is harmful, and concentrations over 2 p.p.m. decidedly so. Phosphatic rocks have a variation in fluorine content from about 0.4 to 4.25%. Apparently the toxicity of various fluorine salts is not the same, since the element in phosphorite minerals, although presumably fluoapatite, $3\ Ca_3(PO4)_2Ca\ F_2$, is from 10 to 20 times as toxic as the fluorine in calcium fluoride. Chickens seem to be less susceptible to fluorine toxicosis than larger farm animals.

Wheeler (397) concluded that steamed bone meal was superior to rock phosphate for growing chicks. Similar results were obtained by Hartwell and Kirkpatrick (146) and Hartwell and Lichtenthaeler (147). Kennard and White (207) found that rock phosphate could replace steamed bone meal in a mineral mixture for laying hens. However Buckner, Martin and Peter (42) found that rock phosphate caused diarrhoea and decreased egg production. Kistler (211) also reported that bone was superior to raw rock phosphate in the production of eggs. Buckner, Martin and Insko (38) reported that 5% of rock phosphate in a chick ration depressed growth and increased mortality. They concluded that rock phosphate was only injurious during the early life of the chick.

From a study of the effect of rock phosphate, containing 3.52% fluorine, on the growth of chicks, Halpin and Lamb (133) found that 1% of this supplement had no effect, 2% resulted in some depression of growth, and 3% was decidedly harmful, although the ash content of the bones was normal. The two lower levels had no influence, but the high level depressed egg production without affecting hatchability.

Kick, Bethke and Record (209) concluded that chicks could tolerate more fluorine in the ration as calcium fluoride than as rock phosphate or sodium fluoride. The fluorine of rock phosphate and of sodium fluoride were similar in action. Toxic levels of fluorine resulted in decreased growth and food consumption, but did not affect the percentage of bone ash. The clotting time of the blood was decreased. A review of fluorine in animal nutrition, including poultry, was given by Kick *et al* (209a).

The Ohio workers set the toxic level at 0.10% fluorine or more and recommended that not more than 1% of rock phosphate should be fed.

Similar results were reported by Hauck, Steenbock, Lowe and Halpin (148) feeding from 0.015 to 1.2% of sodium fluoride. Levels up to 0.15% were ineffective, but greater amounts were toxic, depressing appetite and growth, the high levels lowering serum calcium. No significant effect on bone ash, kidney phosphatase or on the parathyroids resulted. Hens fed 0.96% sodium fluoride lost weight and egg production was depressed. The toxicity of fluorine was enhanced by thyroid feeding, according to Phillips, English and Hart (313).

Phillips, Halpin and Hart (314) showed that the addition of fluorine as rock phosphate to the ration of laying hens resulted in a distinct increase in the fluorine content of the egg. Haman, Phillips and Halpin (134) reported that practically all normal tissues of the hen contain fluorine, bones having the highest concentration and the more active tissues lower amounts. The addition of 0.1056% of fluorine, either as rock phosphate or phosphatic limestone raised the fluorine content of bones 13 to 14 times and from 2 to 3 times the normal in the soft tissues.

It seems obvious that it is not a safe practice to feed rock phosphate or phosphatic limestone as mineral supplements to poultry.

11. SELENIUM

This element is present in a number of plants growing upon certain soils, in concentrations ranging from mere traces to 0.2%. Feeding of such plants or their products results in "alkali disease" or selenium poisoning. A conservative estimate is that any plant product containing 5 p.p.m. selenium is potentially dangerous. The element in the vegetation is derived from the soil due to iron pyrites and other sulphide ores containing selenium, chiefly in shales of the Cretaceous period. Any soil containing 0.5 p.p.m. or upwards, especially in regions of low rainfall is potentially dangerous. Water from such regions may contain 2 to 3 p.p.m. of selenium. It has also been found in rock phosphates.

Tully and Franke (379) have reported that chicks fed on a ration containing 65% of seleniferous grains showed impaired growth, ruffled feathers, nervousness and delayed and reduced egg production; 25% of affected grains was harmless. The eggs produced had low hatchability, almost three-quarters of the eggs which failed to hatch having deformed embryos or monsters, Franke and Tully (111, 112). Similar teratoes were produced by injecting selenium salts into eggs before incubation, Franke, Moxon, Poley and Tully (110). Poley, Moxon and Franke (320) found that a balanced ration containing grains, whose selenium content was 15.15 p.p.m., fed to laying hens caused a loss in weight, due probably to

decreased food consumption, with a decrease in egg size but egg production and ferility were unaffected. In seven days, the hatchability was reduced to zero, but hatchability returned to normal, six days after removal of the seleniferous grains.

Poley and Moxon (319) fed laying rations containing 2.5, 5, and 10 p.p.m. of selenium. With the intermediate level the hatchability was not appreciably affected, although some chicks had wiry down. The high level reduced hatchability to 0, the dead embryos showing short upper beak, oedema of head and neck, missing toes and eyes and wiry down, characteristics of selenium poisoning. No effects on body weight, egg production or fertility were noted. Moxon and Poley (282) investigated the selenium distribution in the body of these hens. This was increased proportionally to the amount in the ration. The selenium content of the eggs was also raised.

12. SULPHUR

Sulphur is chiefly found in the body in combination with proteins, being a constituent of the essential amino acids cystine and methionine. It is present in considerable amounts in the albuminoids such as are found in the hairs, feathers, scales, nails and beak. Only organic sulphur appears to be absorbed so there is no nutritive advantage in adding inorganic sulphur to rations.

In addition to its structural functions, it plays a rôle in cell oxidations by virtue of its presence in glutathione. It is also a constituent of vitamin B_1.

Herrick and Holmes (161) have found that the feeding of sulphur will largely prevent caecal coccidiosis in chicks, if fed in sufficient amount. On the other hand, Holmes, Deobald and Herrick (167) reported that feeding flowers of sulphur to chicks for six weeks, even with cod liver oil, resulted in rickets. Takashi (368a) produced typical calcium metastases and decalcification of the bones of pigeons by feeding sulphur or sulphur-containing compounds.

Marlow and King (251) concluded that the sulphur in egg yolk and white was organically bound and identical, and that nearly all the sulphur in eggs can be accounted for as cystine and methionine sulphur.

Mohler (280a) reported that feeding flowers of sulphur or inorganic sulphur compounds, as done by some poultrymen, had no influence on the moulting period.

13. BERYLLIUM

The reviewer in co-operation with the Toronto Hospital for Sick Children investigated the effect of beryllium carbonate additions to normal chick rations. One-half per cent had little or no effect but 1 and 2% levels reduced the inorganic blood phosphorus to 2.5 and 1.6 mgs., and the bone ash to 36 0 and 32.4% respectively. This effect is due to the formation of insoluble beryllium phosphate in the gut. However the chick seems to be somewhat resistant, since Guyatt, Kay and Branion (123) produced this effect with 0.125% beryllium carbonate in rats. Duncan and Miller (93) were unable to produce this syndrome by feeding up to 50% of soil containing 0.223% beryllium, to chicks.

14. OTHER MINERALS

Although such minerals as zinc and cobalt have been shown to have special functions in mammals, there does not seem to be any proof existant as to their value for chickens. Silicon is a constituent of feathers, but there is no indication that it is ever a limiting factor for feather production. However, it is becoming exceedingly evident that these rarer minerals, even though present in minute amounts, may be extremely important nutritive elements. The rôle of "trace" minerals in poultry nutrition would appear to be a field worthy of further investigation.

In addition to the specto-graphic analysis previously given, Bertrand and Agulhon (16) have reported the presence of boron in eggs. Underhill, Peterman, Gross and Krause (382) gave the aluminium content of eggs as 0.017 mg. per 100 gms. Bishop (25, 26) and Taylor (369) reported the presence of lead in eggs, Mankin (248) that of molybdenum; and Hubbell and Mendel (177) the presence of zinc in eggs, and Bertrand and Vladesco (18) in eggs and the organs of poultry. Straub and Donck (361a) have also reported on the mineral constituents of eggs.

Van der Hoorn, Branion and Graham (386) encountered a new leg deformity, tentatively termed "arthritis" by the use of casein purified by acetic acid leaching in a purified diet. That a mineral or minerals were concerned was indicated by the fact that the inclusion of the ash, made by concentrating and ashing the leachings from the casein, prevented this abnormality. Later results showed that grass ash was preventive also. The factors involved did not appear to be any of the better known minerals including manganese.

15. BLEACHING FUNCTION OF MINERALS—OTHER EFFECTS

Maw (259) has found that bone char has a definite bleaching effect on the colour of fat produced during the fattening period, as well as on the fat already in the body. This action was better than bleaching agents such as fuller's earth and nut charcoal. This finding is particularly important in the fattening of birds for markets which demand a white fat in dressed poultry.

Card and Sloan (57a) could find no effect of mineral supplements on interior egg quality. Hendricks (158a) reported that mineral supplements had no influence on length of wing or tail feathers.

16. EFFECT OF MINERALS ON RESISTANCE TO DISEASE

Clapham (64) has shown that chicks receiving a diet deficient in calcium and phosphorus were less resistant to infestation with *Heterakis gallinae* (caecal worms) than those receiving adequate amounts of these minerals. This is not surprising, since it is generally agreed that a dietary deficiency in any essential constituent lowers the body resistance to disease. On the other hand, Holmes, Herrick and Ott (168) reported that excessive mineral additions were detrimental to chicks infected with *Eimeria tenella* (coccidia). In view of the suggestion previously made, that under modern feeding conditions poultry are more liable to suffer from an excess rather than deficiency of minerals, this finding is noteworthy. The reviewer is tempted to suggest, with little or no proof, that the indiscriminant use of

mineral supplements to poultry rations is not helping, to say the least, to overcome intestinal infestations in poultry. It does seem feasible to point out that it should be within the realm of possibility to make the intestinal tract of growing chicks an unappealing home for parasites. Although the work of Heller and Penquite (155) and Mussehl, Blish and Ackerson (290) indicate that the digestive tract is able to adapt itself to wide variations of dietary conditions without any distinct modification in pH, the author still desires to indulge in theory.

Although the range of the Department of Poultry Husbandry at Guelph has been in continuous use for over 30 years, there has been a decided lowering of mortality in the past few years, due primarily to a decrease in intestinal disorders. Several factors have operated in this connection, and any of these or a combination of all, may have been responsible. First, a continuous supply of fresh succulent green feed is provided throughout the season by the judicial choice of crops and "strip" planting. The colony houses are moved from strip to strip, as the green feed is ready. This involves of course, the ploughing and cultivation of the soil throughout the season, and sunshine and aeration of the soil are valuable "disinfectants". Succulent green feed is mildly laxative and presumably keeps the digestive tract in good working order. Secondly, coarse mashes are used in place of finely ground mashes. This may also serve as a stimulus to the digestive tract. Thirdly, the mineral supplements, bone meal, oyster shell and insoluble grit are fed in separate hoppers, the chickens being allowed to do their own mixing. Under these conditions, disease has been reduced, rather than increased as would be expected from the continuous use of "old" range.

To ensure a good, fast growing crop, the ground is heavily fertilized each year with a complete fertilizer, at the rate of 200 to 300 pounds per acre. English workers (193) have reported that large amounts of fertilizers could be picked up from the soil by birds without affecting health.

17. GRIT

Presumably the function of grit is to aid in the grinding of food and to prevent impaction in the gizzard, but in reality its function is not known. Ever since Spallanzani (357) remarked "we may reasonably conclude that the collecting of pebbles is less the effect of choice than stupidity", the question of the function of grit, its value if any, and the kind to be used, has been debated.

The function of grit was investigated by Mangold (241, 242, 243), by Mangold and Feldin (245), Mangold and Kath (246) and by Mangold and Rudiger (247) who concluded that the presence of small stones or grit in the gizzard allows poultry to derive more benefit from grain. Klee (212) also believed that grit was necessary to maintain birds in good health. Jull (196) also found that grit was necessary for the economical digestion of whole grain. Halnan (128) considered that the efficiency of the gizzard for grinding was increased by grit, and Kruger (219) believed that the presence of grit increased digestion. Although Jaeckel (191) found that the presence or absence of grit did not change the power of contraction of the gizzard, its presence kept birds in better physical condition. This problem has also been studied by Katayama (199), Kato (200), Danilova,

Solun, Chlebnikov and Poliakov (82a), and Ferber and Bruggeman (107). The function of the gizzard has been summarized by Mangold (244) and Henry, Macdonald and Magee (159).

On the other hand, Buckner and Martin (34) and Kaupp and Ivey (202) were unable to demonstrate any benefit from the use of grit, or harm as a result of its absence. Moreover, Buckner, Martin and Peter (48) and Bethke and Kennard (19) have been able to rear chicks on a gritless ration. Burrows (54) has shown that the gizzard itself is not essential to life.

Fritz, Burrows and Titus (113) have found that gizzardectomized birds digested coarse feeds much less efficiently, whereas with finely ground feeds, there was little difference. Bird, Oleson, Elvehjem, Hart and Halpin (24) encountered an abnormal thickening or swelling of the gizzard lining in chicks fed a fine, gritless ration, with a trend towards retarded growth.

Limestone is often sold as grit. Limestone and oyster shell are calcium supplements which dissolve in the digestive tract, particularly in the gizzard under the action of hydrochloric acid. It probably takes from 24 to 48 hours for these substances to dissolve and in the meantime they can serve as grinding agents. On the other hand, grits like granite or quartz are insoluble, and, although they break up by shattering, they probably remain for much longer periods in the gizzard than do soluble grits. Platt and Stephenson (316) reported that limestone grit remained in the gizzard as long as mica grit. Waite (392) considered that limestone or crushed oyster shell could serve in the dual rôle of a calcium supplement and of grinding material.

Although grit is not essential, it seems safe to conclude that its use is a wise practice, for it enables the bird to more efficiently grind up the coarser feed particles, thus releasing the nutrients bound therein. Moreover, if one is willing to grant that grinding is the function of grit, then durability—hardness and insolubility—is the criterion for judging its value. Such insoluble grits as quartz, feldspar, granite and mica are to be preferred. It is unfortunate that limestone is termed grit. If the name grit was reserved solely for insoluble products, then no confusion would arise. Poultrymen who wished to feed "grit" for its grinding value would not be "misled" into purchasing a calcium supplement. Those who wish to feed a "dual-purpose" supplement could do so also.

18. COMPLEX OR SIMPLE MINERAL MIXTURES?

There has been considerable discussion on the relative merits of complex mineral mixtures, made up of many ingredients, as against simple mixtures consisting of such supplements as bone meal, oyster shell or limestone, salt (usually iodized) and occasionally iron. From a survey of experimental evidence, and a consideration of practical poultry experience, it seems evident that simple mixtures work reasonably well. Kennard, Holder and White (206) found that a mixture of 60 parts bone ash, 20 parts calcium carbonate (limestone or oyster shell) and 20 parts of sodium chloride (salt) fed at a 2% level or less, gave satisfactory results. Hart, Steenbock, Halpin and Johnson (143) secured good results from a mixture of 5 parts of raw bone (approximately 50% calcium phosphate), 5 parts of pearl

grits (supplying calcium carbonate), and 1 part of salt. Orr, Moir, Newbigin, Robertson and Murphy (300) and Orr, Moir, Kinross and Robertson. (299) used a mixture of 50% bone meal, 20 of common salt, 20 of chalk, 5 of sulphur, 5 of iron oxide, and a trace of iodine. Phillips and Hauge (315) recommended a mixture of 24 parts of limestone, 15 parts of salt, and either 21 parts of soluble bone, 22 parts of steamed bone, or 42 parts of acid phosphate. We have obtained excellent results with bone meal, oyster shell and iodized salt.

However, until such time as the exact amount of all the rarer minerals required by poultry is known, and until the time when complete soil and crop analyses for all such minerals are known, if ever, one cannot condemn the use of complex mineral mixtures, if the purchaser consideres them economic and provided they are sold as *mineral supplements, no more, no less*. It is quite within the bounds of reason that, under certain climatic and soil conditions, some of the "extra" minerals contained in these minerals may be beneficial. On the other hand, they may be of no value. Only a carefully controlled feeding test would settle that question, and even such a test, conducted in one locality, would not be applicable to all other localities. However, even when a poultryman has obtained benefits from a complex mineral mixture, he must also satisfy himself that such benefits were not due to some of the "common" supplements such as bone meal or limestone, in such a mixture. If they are, then he is not economically justified in paying the higher price for the complex supplement.

The moment such complex mineral mixtures are sold as a "cure-all" or preventive for all poultry disease, they are no longer mineral supplements but are drugs, and as such have no place in everyday poultry feeding. Furthermore, it should be clearly borne in mind that no mineral mixture will ever become the panacea for all poultry ailments.

19. PRACTICAL CONSIDERATIONS

In view of the varying amounts of such protein supplements as meat meal, fish meal or dried milk, and also to the varying mineral content of these products, it is impossible to recommend any definite amount of a mineral or various minerals which should be fed. For this reason, the reviewer strongly advocates the feeding of such supplements as bone meal, oyster shell or limestone and insoluble grit in separate hoppers for both chicks and laying hens and allowing them to partake of such supplements as they desire. Experience has shown that this is a safe practice.

The grains and their products are decidedly deficient in calcium, but usually they furnish adequate amounts of phosphorus. When supplements like meat meal, fish meal or dried milk, in the generally recommended amounts are fed, they usually correct the calcium deficiency, except in the case of laying hens. The calcium requirement of laying hens for the production of egg shell is so high that it is imperative to feed some calcium supplement such as oyster shell. It may happen that rapidly growing chicks may require additional calcium and/or phosphorus, under some conditions, but from ½ to 1% of bone meal and limestone would meet any such requirement. The poultryman should be warned again that even such amounts often will result in perosis. However, if vegetable protein

supplements such as soyabean oil meal are used in chick rations, replacing part of the meat meal or fish meal, the resultant deficiency in minerals, usually calcium, must be compensated by adding 1% of bone meal or calcium carbonate for each 3 to 5% of the "animal" protein replaced.

The amount of salt required will depend also upon the kind of protein supplement used, but the addition of ½ to 1% of salt to mashes either for chicks or laying hens appears to be safe. In inland regions the use of the same amount of iodized salt would seem to be justified.

ACKNOWLEDGMENTS

The reviewer is indebted to Professors W. R. Graham and F. N. Marcellus and to Dr. A. R. G. Emslie for their stimulating and helpful advice and criticism. He appreciates also the kindness of those workers who gave him access to unpublished data. In so far as possible, the original references were consulted, but it is manifestly evident that it would be an impossible undertaking to consult all references. The reviewer has relied in such instances upon Nutritional Abstracts and Reviews, and upon the Abstracting Service of the Institute of American Poultry Industries, 110 North Frankin Street, Chicago.

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FIELD STUDIES OF ALFALFA INOCULATION[1]

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The problem of securing successful inoculation of alfalfa is often perplexing when first undertaken. Partial failure frequently tends to the opinion that the crop is poorly suited to the conditions. From 1915 onwards many puzzling situations were encountered at the Beaverlodge Substation and each in turn has contributed its share of interest.

INOCULATION EXPERIMENTS

The 1928 Seeding

In 1928 at the suggestion of the Dominion Bacteriologist, a seeding of alfalfa was made at Beaverlodge to investigate the effect of inoculation at varying intervals in advance of seeding. The soil-seed method was employed, the soil being obtained on the station premises. The land was a loose black loam. By July the following year readily apparent differences in colour and height occurred in each of the four sets. Plots inoculated immediately in advance of seeding were no better than the uninoculated checks. Inoculation 24 hours in advance of seeding was more successful. Decidedly the best results were obtained from plots inoculated a week in advance of sowing, while plots sown with seed inoculated two weeks in advance about equalled those sown with seed inoculated the day before seeding.

Colour and other growth contrasts were lost by the following season but yields corresponded to those of the first crop. In the third crop the effects continued in a diminishing degree.

In the three-year period the plots sown with seed inoculated immediately before sowing outyielded the checks by only 1.5%. The plots inoculated 24 hours in advance of sowing outyielded the checks by 14.1%, those inoculated one week in advance by 22.3%, while those inoculated two weeks in advance yielded 14.9% more than the checks.

The 1930 Seeding

The scope of the work was amplified in 1930 when a seeding was made on the Johnson farm adjoining the town of Beaverlodge. Both culture and soil-seed inoculation were used. Seedlings were made on three dates commencing May 21. The soil was then mellow and slightly dry. June rains puddled the soil, which was a medium grade dark clay loam, and subsequently shepherd's purse threatened the stand so much that the first two seedings were mown on July 26 and August 4. Other weeds were hand-pulled. Some winter-killing of the alfalfa occurred where the weed growth had been the thickest.

By midsummer of 1931, contrasts began to appear but differing in nature from those of the 1928 seeding. In the 1930 seeding no sharp

[1] Paper submitted for program of the meeting of the Soils Group of the C S.T.A., University of Saskatchewan, Saskatoon, June 1937.
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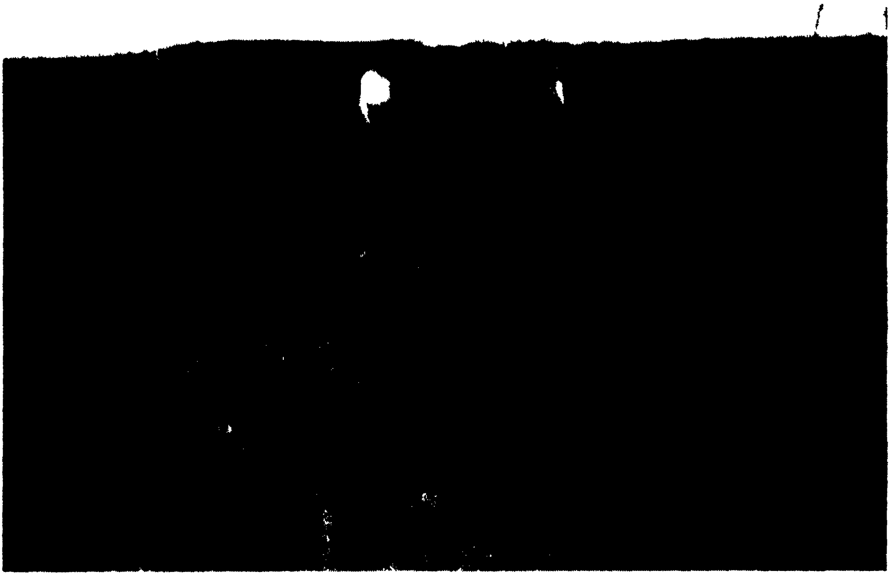

FIGURE 1. Alfalfa, 1930 seeding. Left, culture inoculation; right, soil inoculation.

differences could be discerned as between prompt or deferred seeding after inoculation, but there was an unvarying advantage of soil- over culture-inoculation. This was greatest in the second cropping season (1932) when the check plots were outyielded 130 to 160% by the soil-inoculated plots and 25 to 56% by the nitro-culture plots. The contrasts were at first the most marked on the loamiest areas. On other areas they still existed in the third cropping season.

In one respect the results of the 1930 seeding agreed with those of the former trial. Such contrasts as occurred were slow in manifesting themselves and proved persistent.

Undoubtedly weed growth and soil puddling depressed the yields materially, but it is not entirely clear why plants which were known to have developed nodules in the year of seeding took two or three years to develop the characteristics of well-inoculated plants.

The 1932 Seeding

In 1932 field tests were made on a gray podsol soil on the farm of Clarke Bros., northeast of the station. Soil-seed and culture inoculation were again employed and the seed was sown immediately after inoculation, 24 hours after inoculation and one week after inoculation, respectively. Two cultures were used, one from Ottawa (No. 173), and another, said to be acid-tolerant, received from Dr. H. G. Thornton, of Rothamsted, England. Both cultures were sown with and without calcium di-acid phosphate. The seed was sown in a dry period and very little growth

was made at first. By the end of the season stands were thin, the colour was pale, and no contrasts were evident.

By July 15, 1933, some definite response was noted in the Rothamsted-culture plots. The one sown with seed inoculated by this culture a week in advance of seeding showed distinctly deeper colour and some extra vigour of growth. The 24-hour inoculation showed somewhat less and the immediate inoculation less still, though its response was readily discernible. At this date plots inoculated with the Ottawa No. 173 culture gave no definite indications that the treatment had been successful. The addition of phosphate was without effect.

The contrasts extended and deepened in 1934. The Rothamsted-culture plots again grew much the tallest and continued the deepest green. The Ottawa No. 173 plots darkened considerably, though they did not show as much evidence of strong inoculation as the former. The soil-inoculated plots remained decidedly yellowish in appearance, with almost as little colour as the checks. Still no benefit appeared from the use of the phosphate.

The interval of inoculation in advance of seeding seemed to have no pronounced effect. Stands were somewhat patchy and growth was uneven due to the unfavourable conditions in the year of seeding and to ice killing during the winter of 1933–34.

The 1934 Seeding

A further seeding was made June 12, 1934, on the Clarke farm under favourable conditions. The following inoculants were employed: Ottawa

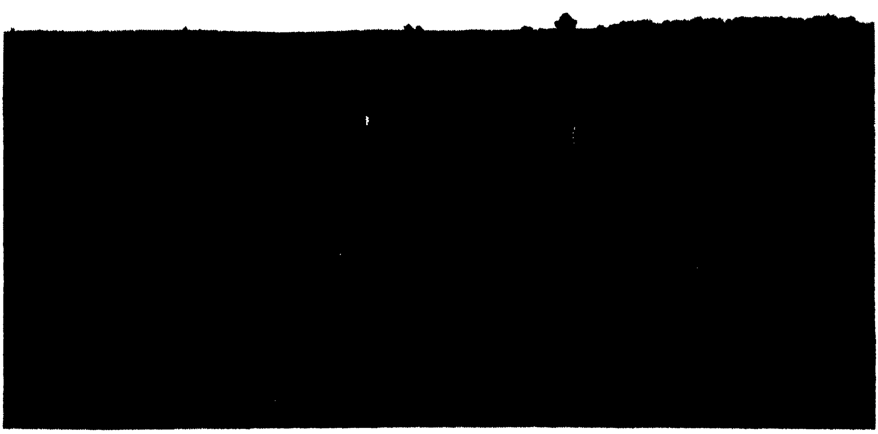

FIGURE 2. Alfalfa 1934 seeding. Left, inoculated with Ottawa mixed culture; center, not inoculated; right, soil inoculation.

mixed culture; Ottawa No. 173 culture; Beaverlodge No. 3 culture (isolated from nodulated plants grown at Beaverlodge); Rothamsted acid-tolerant culture; soil (from the Beaverlodge substation); check (no inoculation).

Each of these was compared in three intervals of inoculation in advance of seeding, *viz.*, inoculation one week in advance; inoculation 24 hours in advance, and inoculation immediately in advance. The soil was dry when the seed was applied but the sky was overcast and a heavy shower fell within a few hours.

On August 28 the Ottawa mixed culture, the Beaverlodge No. 3 and the Rothamsted cultures seemed to be distinctly the most effective. The checks were rather pale in colour, while the soil-inoculated plots showed occasional green plants. Ottawa No. 173 proved slightly better than the soil but hardly equal to the other three inoculants.

In 1935 the Rothamsted-culture ranked first at the beginning of the season, closely followed by the Ottawa mixed and the Beaverlodge No. 3 strains. During the six-weeks' period between the first and last observations there was a gradual narrowing of these differences so that by July 17 there was little to choose in appearance among these inoculants. The soil-seed plots ranked next in order and improved their comparative position as the season advanced. The Ottawa No. 173 and the check plots took fifth and sixth places, respectively, both ranking much below the other four treatments. They failed to improve as the season progressed.

Although conditions seemed reasonably uniform at time of seeding, the plot arrangement seemed best adapted to a study of the effect of inoculants rather than of the results of pre-inoculation periods.

Yields agreed pretty well with the field notes. On the average of six plots representing a duplicate test with each of three inoculation pre-intervals the Rothamsted culture produced 3771 pounds of hay per acre; the Ottawa mixed 3660 pounds; soil-seed, 3289 pounds; Beaverlodge No. 3, 3133 pounds; Ottawa No. 173, 2668 pounds; and the checks, 1946 pounds, notwithstanding some accidental inoculation of the latter.

By September 25 the variation that had been so apparent throughout the season's first growth was hardly noticeable in the aftermath. Infestations which had before been limited to the margins were now general over most of the area. The extreme wetness of the summer undoubtedly favoured bacterial diffusion.

FINDINGS OF OTHER WORKERS

The effect of holding inoculated seed has been studied by a number of workers (1, 3, 5, 6, 7, 8). Although there is an immediate decrease in the number of organisms adhering to the seed coats, viable bacteria may be retained after six months or more, capable of producing nodules. Tests at Ottawa (5) have shown that the nodule-forming capacity tends to decrease with time of holding, though the decline is less rapid than that of the organisms themselves. It was also found that with lower temperature of storage the nodule forming capacity decreases to a less extent than at higher temperatures.

In a field trial, following inoculation four days in advance of sowing, Fred, Whiting and Hastings (4) found about one-fourth of the plants

vigorous, with the remainder small and lacking nodules, and attributed this to the death of bacteria before reaching the soil. On the other hand Thornton (8) found that although storing of inoculated seed for 28 days halved the number of nodules, there was no significant reduction in yield.

Thornton stresses the importance of proper soil aeration, high moisture content, and the action of phosphates, which stimulate nodulation and root development. From tests in different parts of England he concludes that it is likely the spreading of bacteria is affected by season, and occurs only under suitable conditions of soil moisture and temperature. The soil reaction is important, particularly in its bearing on the adaptation of bacteria. Some strains may form nodules at much lower pH ranges than others, suggesting that in some cases there may be more acid-tolerant strains in the soil than found in cultures usually supplied. Alway and Nesom (2) found that in some land soil spreading gave much better inoculation than pure cultures and that a second sowing of alfalfa succeeded well after the first sowing had failed.

DISCUSSION OF THE BEAVERLODGE RESULTS

Since in commercial practice it is occasionally necessary to hold inoculated legume seed some days before sowing, the 1928 seeding had a practical basis. Prepared culture was not available at the time and the soil-seed method of inoculation was resorted to. The results obtained cannot be entirely explained, but suggest that the bacteria on moistened seed may have gone through a period of incubation following the inoculation and that this continued, at least as long as the soil remained moist.

The 1930 seeding was likewise on dark soil where the chance of previous inoculation was slight. Here adverse conditions affected the stand, prohibiting fine comparisons, but it was significant to observe the paired contrasts of the results of culture and soil inoculation, with the darker colourings spreading first from the loamiest areas. The bacteria transferred with the soil in each test must have included strains better adapted than those supplied by the culture, yet it is not clear why it required in some instances at least three seasons to achieve its full result and why in places the inoculated plots gave scarcely better results than the checks.

The introduction of the Beaverlodge No. 3, Ottawa mixed, and the Rothamsted strain to the Clarke farm, in contrast to the Ottawa No. 173 strain, may serve to explain the relatively poor showing made by the culture series in the 1930 seeding. In view of this it would seem to be necessary to determine the adaptive range of any strain of nodule bacteria before prescribing it for use, and would suggest the greater safety of using a composite of several strains until the superiority of any one was definitely established. Peace River soils are far from uniform. Mostly they are podsolized and tend to be slightly acid in reaction. In such a case a culture of mixed strains might be safest in general practice.

SUMMARY

The results of six years testing under field conditions confirm the findings of other investigators that there are pronounced differences in the vigour, adaptability, and beneficial effects of various stocks of nodule bacteria, and suggest the differentiation of these for specific conditions.

Soil-seed inoculation applied by the glue method gave much better results than culture inoculation in some seedings but was not uniformly better. Lacking a handy supply of a suitable strain of culture, soil-seed inoculation may be used to advantage but prepared culture would seem to be preferable, if only in minimizing the danger of weed-seed and disease transference.

Inoculation of legume seed several days in advance of sowing may be satisfactory, but this may depend somewhat on storage conditions, and possibly other factors.

The addition of calcium di-acid phosphate to the seed when the culture was used produced neither positive nor negative results.

Ample moisture and good cultural conditions are favourable to the securing and spreading of effective inoculation.

Artificial inoculation may be done according to rule without proving effective. Under some conditions it may not become fully effective for two or three years.

The grey woodland soils will produce satisfactory stands of alfalfa under suitable management.

On land not previously inoculated no cultural or bacterial treatment can be used with guaranteed success. If the first attempt results in failure the sensible course is to try again on the same gound, taking advantage of the bacteria introduced and multiplied by the first attempt.

ACKNOWLEDGMENTS

Due acknowledgment is made to W. D. Albright, Substation Superintendent, who has followed the results from season to season with the writer, and to Dr. A. G. Lochhead, Dominion Bacteriologist, for valuable suggestions received during the course of the experiment.

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THE RELATION OF WIREWORMS TO POTATO GROWING IN THE PRAIRIE PROVINCES[1]

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Wireworms cause important losses annually in the majority of gardens and potato fields in large sections of Western Canada. This is especially true in the prairie area and over a broad margin of the adjacent park belt, where it applies to all but the heaviest soils. In the latter, as well as in the densely wooded country and in much of the irrigated land of Alberta, the damage is less severe and less common although occasionally of serious proportions. In general, observations indicate that as with small grain crops, the rate of wireworm damage is considerably greater to potatoes which have been planted on land that was summer-fallowed the previous season.

The major damage to potatoes is in the loss of market value due to disfiguration of the tubers, but sometimes the yields are also materially reduced. In recent years the damage has increased, reaching such magnitude in 1936 that should it continue on this scale, it may force the abandonment, in some sections, of commercial production of potatoes. For example, in the Saskatoon district in 1936, fields up to 75 acres in area suffered as much as 50% reduction in the yield of marketable tubers. In considerable measure, this can be attributed to an increase in the abundance of the pest probably connected with the general neglect of weeds in fallow land during the recent depression period. In part it is undoubtedly connected with the direct influence of drouth conditions upon feeding habits, and it is to be expected that the injury will be materially less during seasons of abundant moisture at critical periods. However, the problem is really a "permanent" one because the characteristics of the chief species, the prairie grain wireworm (*Ludius aeripennis destructor* Brown), eminently fit it to be a major pest of potatoes in this region, the net result being that the problem is most acute in the areas and fields which in all other respects are best suited to the production of potatoes.

Because potatoes are usually planted in old grain fields, the wireworm problem of potato growing is inseparably linked with the wireworm problem of grain production. Consequently, extensive field studies on the latter have provided an essential background from which to approach the problem with respect to potatoes. Such studies have been supplemented by observations in wireworm-infested potato fields and by preliminary experiments with baits and soil fumigants. Investigation of this problem is continuing, our knowledge in several important directions being definitely inadequate.

SUMMARY OF CONTROL RECOMMENDATIONS

The solution of the problem (1) depends upon either *avoiding* severely infested soil through careful selection of fields, or sufficiently *reducing* the

[1] Presented before the Horticultural group of the 17th Annual Convention of the Canadian Society of Technical Agriculturists at Saskatoon, Saskatchewan, June 1937.
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heavier infestations before the planting of potatoes. The latter can usually be accomplished gradually, but cheaply, by frequent clean summer-fallowing, and sometimes by means of baits; or quickly, but at considerable cost, by the use of crude naphthalene as a soil fumigant.

Choice of Land

Selecting land "safe" for potatoes is often feasible because some of the main factors, such as soil type and cultural practices, which largely determine wireworm abundance, are known.

There is a high probability of freedom from serious wireworm damage in the following types of fields: where good clean summer-fallowing has been practised about every three years, or oftener; in heavy clay soil, except where recently broken from native or tame grass sod; in the more dense park areas, land which has been under clean cultivation for from four to ten years; and in irrigated sections, fields of medium or heavy soil which have been irrigated at least three times annually for several years.

On the other hand, there is a high probability of serious wireworm damage occurring to potatoes planted in the following types of fields: those which have remained "idle" for several years; where, as a rule, weeds have been poorly controlled during the summer-fallow years; where summer-fallowing has been infrequent, three or more crops being grown in succession; where grass has been grown continuously for several seasons; and in willow-scrub land which has been under cultivation for less than three years.

In the severely-infested districts, special care should be taken to avoid fields with unfavourable histories, even though at the time of planting they appear attractive as potato land. A valuable "indicator" of the importance of the wireworm infestation in a field is the amount of damage occurring to young wheat plants of the first crop after summer-fallow. Such observations should be made on fields which are being considered for future use in potato production. Wherever appreciable thinning by wireworms occurs to wheat on fallow, potatoes are likely to be severely damaged. The symptoms of wireworm injury to wheat are characteristic and easily recognizable (4).

Summer-fallowing

From the standpoint of wireworm control (3, 4), the essential measures in summer-fallowing seem to be, keeping the field absolutely free of all large weeds from the middle of June to at least the end of July, presumably to starve the newly-hatched wireworms which are then seeking their first food; thorough shallow tillage during the last half of July to destroy a portion of the pupae which are found at that time in the top three or four inches of soil; and ensuring that all tillage is never deeper nor more frequent than is necessary for the control of weeds, frequent deep tillage appearing to favour the survival of the pest.

Two such summer-fallowings, three years apart, have been known to reduce a severe wireworm population by fully one-half, and there is evidence that summer-fallowing in alternate years, or in two or three successive years, would still more quickly reduce infestations.

As long as proper summer-fallowing continues to hold an essential place in any sound permanent farming program in the Canadian Prairies,

the above procedure has the advantage of being not only persistently effective in controlling wireworms, but also highly economical in that it involves no additional costs but only practical modification of normal procedure.

Baiting with Potatoes

As an alternative method, for small areas, baiting with potatoes has been found to have some value in reducing wireworm numbers. Unfortunately, the effectiveness of this method is variable, depending upon several factors which are not yet fully understood though it is evident that the moisture factor is of great importance. But the method is cheap and applicable during crop years prior to the regular planting as well as when the land lies fallow. Preliminary tests on both lightly and severely infested fields have shown that, during persistently dry weather, single baitings frequently fail to trap more than 5% of the wireworms in the baited area. On the other hand, excellent control by this method has been obtained[4]. In this instance the authors observed that the main catch was secured during a period when a large proportion of the wire worms had moved into a superficial layer of moist soil, after a good rain which followed a considerable period of dry weather.

Soil Fumigation

Fumigation with crude naphthalene is recommended for land where the immediate and virtually complete destruction of wireworms is of sufficient economic value to justify a rather heavy outlay for materials and labour. Just how long such land would remain free from economic infestations would depend largely on the farming (or irrigation) practices subsequently adopted; but, in dry land farming with proper summer-fallowing at least once every three years, it is believed that the pest could be held below serious proportions for several, or even many, years. The present evidence is that reinfestation of the prairie grain wireworm by either migration or multiplication is very slow.

The use of crude naphthalene under dry land conditions in the Prairie Provinces (2) is a modification of the method developed by Lane (4) for the irrigated* sections in the state of Washington. Successful use of this material appears to depend upon the following principles of operation:—

1. The application of the naphthalene when the soil temperature is high enough to ensure both larval activity and rapid formation of effective concentrations of gas;
2. The ploughing of the material into the soil, deeply enough, usually 7 inches in Saskatchewan, to permit placing a portion of it as deep as the wireworms are likely to be at that season;
3. The thorough working of the naphthalene through the soil, immediately after ploughing; and
4. The use of enough naphthalene to give lethal concentration of vapour throughout the wireworm-infested soil layer.

[4] Mr. H. J. Kemp, cerealist at the Dominion Experimental Station, Swift Current, Sask., reports that, in 1930 and 1931, through the use of potato baits, a heavily infested area was rendered suitable for cereal variety test purposes, as many as thirteen wireworms being taken at a single bait piece. This plot area of one and one-half acres is reported to be still free from serious wireworm numbers.

Lane recommends that the soil be 70° F. or higher at 6 inches below the surface. Thus, in the Prairie Provinces, the use of the method is generally limited to midsummer and to fallow fields. He also regards the thorough working of the soil after treatment as a very important point since naphthalene vapour apparently does not spread far in the soil with killing effect. For this reason two thorough and deep operations of a one-way disc or a duckfoot cultivator may be preferable, although one such operation has been known to give good results.

The application of eight hundred pounds per acre of approximately *95% pure naphthalene* is recommended by Lane for the treatment of a 12-inch depth of moist soil. This rate should be ample for use under any conditions on the Canadian Prairie. In fact, the preliminary tests (2) indicate that half this rate may here be adequate, at least in very dry soil and under our usual conditions of infestation which require treatment only to a depth of about 7 inches. Even at the lower rate, the cost of materials, at current prices, is some twenty dollars ($20) per acre; to which, of course, must be added the considerable expense of the thorough deep tillage that is required.

Field tests with calcium cyanide under Saskatchewan conditions in 1934 and 1935 failed to give satisafctory control of wireworms. Over 200 pounds per acre of "Cyanogas-G Fumigant" was drilled-in adjacent to rows (18 inches apart) of living wheat seedlings which served as bait to concentrate the wireworms. The material was applied both with a regular farm seed drill and with a hand seeder, these being the only seeding implements normally available to farmers in this area. As a consequence of the poor results secured and the excessive cost of the materials, it is evident that calcium cyanide cannot be recommended for wireworm control in the Prairie Provinces.

SUMMARY

Wireworms cause important losses annually to potatoes in the Canadian Prairies, especially in those areas and fields which in all other respects are best suited to the production of this crop. During the recent drought years both the infestations and the rate of damage have increased, reaching such proportions in some districts as to threaten the abandonment of potato production on a commercial scale. The solution of the problem depends upon either avoiding severely infested soil through proper choice of land, or reducing the heavier infestations, either gradually and cheaply, by frequent clean summer-fallowing (which may be supplemented, in small areas, by the use of baits), or rapidly but with increased expense by fumigation with crude naphthalene which has been found to give effective control under dry-farming conditions.

ACKNOWLEDGMENT

Mr. J. W. Marritt of the Dominion Seed Potato Certification Service, materially assisted the authors in appraising the problem in northern Alberta and in northwest Saskatchewan, and has kindly reviewed the manuscript.

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BOOK REVIEW

Smith, Kenneth.—A Text Book of Plant Virus Diseases. J. &. A. Churchill Ltd., 104 Gloucester Place, Portland Square, London.

The *Textbook of Plant Virus Diseases* by Dr. Kenneth Smith of Cambridge University, England, (J. & A. Churchill Ltd., 1937) is a timely addition to the literature of plant pathology. Owing to the multiplicity of papers that have been published during recent years describing plant viruses and virus diseases, plant pathologists have found it difficult to decide whether viruses discovered locally have not been studied and described already elsewhere. Smith's textbook brings together all the principal descriptions of plant viruses and virus diseases in a systematic manner based upon the virus nomenclature scheme suggested by Dr. James Johnson of Wisconsin at the last International Botanical Conference in Amsterdam. The viruses are given the generic name of a host and arabic numerals to indicate distinct types and letters in addition where distinct strains of a major type are described. This method preserves the continuity of current practice, *e.g.*, "Nicotiana virus 1A" and "1B" represent two strains of "Johnson's Tobacco virus 1." The generic name chosen represents the host upon which the effect of the viruses was first described or upon which subsequent descriptions of virus symptoms were more adequate. Owing to the support already given this scheme of nomenclature by both American and European workers, the publication of this textbook will tend to establish order in the chaotic condition of the virus literature with respect to nomenclature.

Very few descriptions of plant viruses have escaped review in chapters I to VII inclusive. Dr. Smith is fully aware that he has given arabic numbers to signify distinctiveness to viruses that later may be proven to be closely related strains of the same basic type. Already, in spite of the limitations of serological methods in virus classification, relationships have been established by this method between plant viruses formerly considered distinct.

The description of the insects involved in virus transmission and their life histories in chapter VIII serves to focus attention upon insects as vectors of virus diseases, a field that is a challenge to scientists. In spite of the highly infectious character of "Solanum Virus 1" as judged by plant juice transfers and the fact that the majority of European and practically all American varieties of potatoes are infected, no one has secured satisfactory evidence that this virus is transmitted from plant to plant by thrips or other insects.

The final chapter deals with a large group of plant species that exhibit chlorotic or other symptoms that suggest virus infection but wherein the infective character of the disease has not been proven.

A three-column appendix of 37 pages is included to assist students in the diagnosis of virus diseases. All common hosts are listed alphabetically opposite brief descriptions of the diseases to which they are susceptible and the names of the viruses involved.

W. Newton.

ERRATUM

In the December 1937 issue, Volume XVIII, No. 4, the illustration over the caption for Figure 19, page 192, belongs to Figure 20, page 195, and the illustration over the caption for Figure 20 belongs to the caption for Figure 19.

SCIENTIFIC AGRICULTURE

Vol. XVIII FEBRUARY, 1938 No. 6

WHEAT IN CANADIAN AGRICULTURE[1]

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[Received for publication December 4, 1937]

A recent contribution to a series of articles on the wheat situation in Canada appearing in the *Financial Times* contained part of this material. The part previously published was responsible for the more elaborate report presented before the Royal Grain Enquiry Commission and here included. Earlier discussions in the series though discussing the wheat situation from various angles have not endeavoured to define the importance of wheat in the agriculture of the country. Hence this title. Obviously any attempt to fit the wheat situation into the general picture of agriculture must be somewhat sketchy on account of the brevity required. Yet at this stage some such endeavour appears well worth while.

There is, of course, no insinuation here that previous discussions have entirely neglected to stress the importance of wheat in the agriculture of the country. The probability is that it has been over-stressed. Over-stressing the importance of wheat, over-expansion of wheat growing in relation to other crops, and as well the "wheat complex" that has prevailed in this country during the post-war decade, have all helped to throw the agriculture of the country out of balance. Happily there is evidence, as we shall later see that a more reasonable balance to agriculture has been brought about during the last half decade.

DEMAND

The most important factor in the wheat situation is the probable future demand. A recent study (June 1936) by the Food Research Institute of Stanford University on Wheat Utilization since 1885 furnishes some valuable information on this point.

From 1885 to 1913 per capita consumption of wheat (ex Russia) increased by six-tenths of a bushel per annum. By 1935 it was over one-third of a bushel less per annum than in 1913. The decline in per capita utilization was attributed to consumption of less farinaceous foods with the rising standard of living and the slower rate of increase in total use attributed to the slower rate of increase in population. During the period of low prices, considerable increase occurred in the use of wheat for feed for live stock. The statement is made that wheat growers cannot reasonably expect to expand wheat acreage in the next decade and at the same time avoid accumulation of surplus stocks and a low level of price.

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[1] Contribution from the Faculty of Agriculture of McGill University, Macdonald College, Que., Canada. Journal Series No. 90.

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It is frequently claimed that it is impossible to produce a surplus of wheat. The argument is that no matter how much is produced it will all be used. Those belonging to this school of thought consistently oppose, in season and out of season, any endeavour to reduce supply locally. One of the stock arguments is that if the local production is reduced, then Argentina or Australia will simply expand area and take up the slack. This latter claim is exactly what would happen. But not if there is no possibility of providing a surplus. If there can be no such thing as a surplus of wheat in the world, as some argue, then, what difference does it make what amount other countries produce?

What we suppose is the meaning of this argument is that there is no possibility of producing too much wheat in Canada. The question would be clearer if the concession were made that there is only a limited amount of wheat required in international trade at the moment or in prospect, and the question of moment is what share of this trade it is proposed to secure. It might be expected that we could by this time agree upon this point. Such, however, does not appear to be the case.

The specialists in the study of the wheat situation have presented many arguments in support of two different dangers. One is the fear or danger of producing too much wheat. The other is the fear or danger of not producing enough.

There is nothing new or strange about such an argument. This identical controversy has been carried on now for a number of years. This argument is by no means limited to wheat, as many other farm products have lived through the same experience and in none of them has the final word yet been uttered.

One limiting factor to the plausible presentation of these two conflicting ideas in regard to the wheat situation is that it does not get us very far, as it furnishes a poor foundation for a working policy in regard to the future. Notwithstanding the opposing views which have been kept before the public so persistently, there has developed some degree of unanimity of opinion on some points that are now influencing public policy in regard to wheat growing in this country.

PRICE AND SUPPLY

What is the use or need of worrying whether this, or any other country for that matter, should produce either too much or not enough wheat? The price forthcoming should, if not interfered with, settle that. It is the special business of price to bring forth the required supply. If and when the supply is such as to cause what is termed a "situation", or "crisis", or an "emergency", and all these terms have been used in regard to wheat in various parts of the world in recent years, then there are two possible reasons for this development; either price has failed to work automatically to regulate supply, or price has not been allowed to function freely and the interference with price previously referred to has come into play with varying results according to the type of the interference adopted.

All are aware of the numerous arbitrary interferences with the price of wheat during recent years in various countries of the world. It is necessary here to note that, if all are as thoroughly aware of the arbitrary interference with price in other goods, some of them conveniently forget this

when recommending a laissez-faire policy in regard to wheat and other farm products. With the trend toward regulation of wages in industry in this country, with the stability of prices of manufactured goods and the costs of distribution of goods in general including farm products in this country, with the regulation of prices of farm products in other countries and the quota restrictions of many countries that are important markets for surplus farm products, the advocates of a let-alone policy for agriculture appear to have a difficult position to defend.

If a freely competitive policy were allowed in all branches of industry and a free flow of labour, capital, and goods allowed from industry to industry, as well as from country to country, the let-alone policy would be logical. Such a situation never has prevailed, and the world has recently moved so far in the opposite direction, whether rightly or wrongly, that it appears necessary for Canada to fall into step.

Since 1930 there has been much less regulation in Canada of the prices of farm products than in some other countries. If the opponents of all interference with prices were right, then we should be much better off locally than in these other countries. The evidence does not support this claim. Allowing farm prices to fall so far out of line with the prices of other goods as occurred from 1930 to 1936 was unnecessary, unwise, and ineffective. Unnecessary, as some other countries did not allow this to occur even though to prevent it they had to interfere by arbitrary regulations. Unwise, in that there has developed in the wheat growing region of this country a condition which ten years of prosperous times will not overcome. (And here we do not refer to the drought areas: reference is more definite toward Alberta, where crops have not been a failure. Reginald McKenna in a recent visit said what Alberta needs is harvests. He was only partly right. Alberta has not suffered from crop failures during the past eight years. What Alberta has suffered from particularly is low prices of farm products.) Ineffective, in that the depression was felt particularly by the agricultural industry, where wages dropped to 50% of the pre-depression level and have not come back as promptly as have wages in other industries.

This is all water under the bridge now; yet it will be unwise to forget all about this experience when discussing future policy, and particularly for the reason that in 1929 the wheat growing areas had just enjoyed half a decade of good crops and high prices and were in comparatively good shape to meet adversity. The period of low prices lasted so long that the value of the agricultural plant declined tremendously. With declining values of farms, debts increased, private credit was largely replaced by public funds and thus the way paved for an increase in public assistance and regulation.

The long period of low prices of wheat from 1930–1936 was partly due to the increased supply brought about by the increase in area induced by the high prices prevailing from 1925–1929. The adjoining figures may make this clear.

WHEAT AREA CANADA, ARGENTINE, AUSTRALIA COMBINED

	Millions of acres
Av. 1910–13	33
Av 1924–30	53
1930	63
1931	57
1932	63
1933	61
1934	55
1935	48
1936	55

Price resulted in expanding acreage in the three leading exporting countries from 1924 to 1930. From 1930 to 1935 price resulted in reducing acreage in these countries from 63 to 48 million acres, a reduction of 15 million acres, or almost one-quarter. Just what happened in Western Canada during this time will be examined in more detail. A result such as this indicates that price has some regulating effect on supply in these three leading exporting countries. This is by no means to suggest that the recent dry seasons have not also had effect upon price. It is to suggest very emphatically, however, that the price of wheat has a very salutary effect on the supply forthcoming. Not only has the price of wheat an effect upon the supply but also the price of other farm products which the wheat grower may resort to when compelled to do so. This brings up another phase of the situation which must be examined.

ALTERNATIVE OPPORTUNITIES

It has often been asserted that when wheat prices decline all farm products suffer as well. They do as a rule. But by no means regularly or to the same amount. For this reason it is ridiculous to treat wheat altogether apart from other farm products.

The farm price of wheat in Canada for the five years from 1930–1934 was 45.5 per cent of the previous five-year level. For the same period the price of potatoes was 44.4 per cent of the earlier period. This was the only staple farm crop that declined more than wheat during this period. Other declines are given: barley to 50.9, oats to 51.0, sheep and lambs to 54.8, eggs to 58.6, butter to 59.6, hogs to 61.3, calves to 61.9, beef cattle to 67.3, and sugar beets to 80.4 per cent of the earlier level.

During this period the price of grains declined to about half the level of the previous five years, butter and eggs by slightly over forty per cent, hogs and calves almost the same, while beef cattle brought over two-thirds the price of the earlier period. It was to be expected that with this difference in price some shifting would occur in farm production. It is now possible by the use of the census figures for 1936 to measure the extent of the shift during the last half decade as well as to compare it with earlier periods for the Prairie Provinces.

WHEAT AREA OF PRAIRIE PROVINCES

Millions of acres

Wheat area, census years		Farm price, 5 yr. av.	Expansion in wheat area
1911	10		
1916	14	1911–1916 76¢ per bu.	+4
1921	19	1916–1921 183¢ per bu.	+5
1926	22	1921–1926 95¢ per bu.	+3
1931	26	1926–1931 88¢ per bu.	+4
1936	25	1931–1936 48¢ per bu.	−1

During the period from 1931 to 1936 the area devoted to wheat in the three provinces declined by 761,000 acres, or slightly over three-quarters of a million acres. This is the first five-year period that has recorded such

a decline, according to census records. It is reasonable to suppose that price had some influence on this result. During this same period the total area in field crops increased by 177,000 acres, so that some other field crops must have been substituted for wheat. Acreage of barley in 1936 was some 500,000 more than in 1931 and the area in oats nearly 400,000 acres more than in the earlier year.

Since 1928 an estimate of the new breaking in the prairie provinces has been annually recorded. During the first five years of that period, that is from 1928 to 1932, the average area of new breaking added annually was 1,267,000 acres. During the last five years, from 1933 to 1937, this annual addition averaged 460,000 acres. This slowing up in the rate of expansion has been to a certain extent attributable to price and has no doubt also had some influence on the reduced yields per acre, as the proportion of new land has been smaller in recent years.

Census figures of 1936 show a marked increase in cattle in the Prairie Provinces as compared with 1931. The increase in total cattle amounted to over 900,000, or 31 per cent, while the increase in cows in milk or in calf was some 427,000 or 35 per cent. Some decline in number of hogs was recorded, but this may be partly due to the recurrence of hog cycles, which prevents census years only from being as fair a measure of hog production as other classes of live stock. Generally it is apparent that considerable switching away from growing grain for sale occurred during the period from 1931 to 1936. This is important, as many of those who discuss the wheat problem maintain that there are no alternative possibilities applicable to western Canada. This assertion has been so frequently made that the authors no doubt believe it themselves by this time. That, however, is not important; but what is more dangerous is that they may have by this time persuaded some of the farmers themselves to believe it.

Past records reveal that when wheat is over a dollar a bushel at the farm, no other line of farming receives much attention in Western Canada. Records also reveal that a period of low wheat prices expands other lines of farming. There are well known limits to the amount of switching possible. That some is possible has been demonstrated during the period 1931–1936. Why we know it is possible is because it has been done.

The development of other lines of farming is, in the long run, the salvation of the grain grower. There is no method of getting rid of a grain surplus equal to turning it into meat and dairy products. Those who have advocated this method of treating the wheat problem will no doubt, in the long run, prove the best friends of the grain growers generally, as it will promote a better balanced agriculture.

THE EFFICIENCY OF THE GRAIN GROWERS

Having in mind a better balanced agriculture and conceding that the national industry became unbalanced from 1916 to 1930, then, it may be of interest to examine the development of the technique of wheat growing in particular and grain growing in general during recent years. The method of growing grain has altered greatly in recent years. In 1910 the number of bushels of grain grown per person employed in agriculture averaged 780 bushels for the three prairie provinces. In 1920 the amount per person engaged in agriculture was 1,180 bushels, and in 1930 was 1,388

bushels, or nearly twice the amount per worker produced in 1910. This increase has been made possible by larger farms and more machinery. This season the author saw some wheat that was harvested with a "header" running 4 bushels per acre and good for a grade of No. 3. The only possibility of profitably harvesting such a light crop was with a header, as there would be no chance of binding such a light crop into sheaves. The future of wheat growing in dry areas is based on the modern machinery now available, the only method physically possible or economically profitable to garner such light crops. This is in line with the recommendations of a committee that has investigated the problems of the "dust bowl" of the United States for the past three years. This means that the only possible way of profitable wheat growing in dry areas is by large mechanized farms. In Australia, where the rotation in the dry areas, according to Sir Daniel Hall, is one year wheat, one year weeds, and one year fallow, it was found a long time ago that a family wheat farm in the dry area must consist of around twelve hundred acres.

NON-RESIDENT FARMS

If grain growing in dry areas is of necessity a mechanized job, then, there would appear to be no need for the operator to live on that particular farm throughout the whole year. Such a farm could be run most economically in connection with another farm where live stock could be kept and some returns secured during the winter months. There is no reason whatever why a small irrigated farm devoted to beef raising could not be operated in connection with a large grain-growing mechanized concern. Perhaps this is developing, as the 1931 census lists the non-resident farms of Canada as follows.

NON-RESIDENT FARMS

—	—	Percentage of total
Canada	57,191	7
P.E.I.	779	6
N.S.	1,415	4
N.B.	969	3
Quebec	9,338	7
Ont.	14,556	8
Man.	3,905	7
Sask.	16,427	12
Alta.	9,298	10
B.C.	504	2

These figures show that nearly half of the non-resident farms are located in the two provinces of Saskatchewan and Alberta. Again, the possibility of this procedure is maintained largely because it is already being done.

The practical doubling of the output of grain grown per worker in agriculture in the Prairie Provinces in twenty years is striking testimony of the increased efficiency of the grain grower. Yet if Canada is to maintain a major portion of the at present limited requirements of international trade in competition with countries such as Argentina, where we are told two-thirds of the crop is now grown within eighty miles of the seaboard, every possible means of increasing the efficiency of production will be necessary.

Recent census returns reveal some of the results of the half decade from 1931 to 1936 on the agriculture of the three Prairie Provinces. This record should be studied carefully by all interested in the status of the

agricultural industry of Canada. Some of the main points from these records are here summarized:

Trends 1931-36 Prairie Provinces[3]

Census returns of 1936 reveal that during the half decade from 1931 to 1936:

1. The value of land in the three Prairie Provinces fell by $328 million, or 22 per cent.
2. The number of farms operated by owners fell by 6,958, or by 3.7 per cent.
3. The number of renters rose by 14,448 or 34 per cent.
4. The number of farms partly owned and partly rented rose by 4,620 or 10 per cent.
5. Considering only the entirely owned and the entirely leased farms, 4 million acres passed from ownership to leasehold in the five years, or a gain in leasehold of 24 per cent.
6. The total number of farms increased by 14,444, or by 4 per cent.
7. The acres in field crops increased by 177 thousand acres, or 0.4 per cent.
8. The area devoted to wheat fell by 761,000 acres, or 3 per cent.
9. The area of new breaking was estimated at 1,300,000 acres in 1931 and at 473,000 acres in 1936, a decrease of 71 per cent.
10. The number of milk cows increased by 427,000, or 35 per cent.
11. The total number of cattle increased by 900,000, or 31 per cent.
12. The number of hogs decreased 600,000, or 25 per cent.

Land Value

During the five years 1931 to 1936, land values declined in the Prairie Provinces over $300 million, or over $1,000 per farm. This record warrants an examination of where land values were before this decline occurred. The following table shows the record over a long period of time.

LAND VALUES PRAIRIE PROVINCES

—	Area occupied millions of acres	Total value of land in farms millions of dollars
1911	58	$1,238.
1921	88	2,051.
1926	89	1,574.
1931	110	1,500.
1936	113	1,172.

This almost incredible record shows that while the area became almost twice as great since 1911, the total value actually decreased during that time; since 1921 an addition of 35 million acres was accompanied by a loss in land value of $879 million.

The expansion in area in the period here referred to occurred during the decade from 1911 to 1921 and the half decade from 1926 to 1931. Yet during the later period an addition of 31 million acres coincided with an actual decline in value of the total occupied area. During the two post-war depressions, that of the years 1921 to 1926, and from 1931 to 1936, expansion was limited and the decline in land values marked. The period from 1911 to 1936 gives the best example of people running fast to keep from slipping backward that has come to my notice.

[3] Canada Year Book 1937, pp. 272-273.

Wheat Area

Wheat growing has absorbed the major portion of the expansion in farming in Western Canada. The area of wheat shows a somewhat similar picture to that of the expansion of total area. During the period from 1931 to 1936 the area devoted to wheat declined about three-quarters of a million acres. This was the first five-year period that registered a decline, and the price prevailing is probably ample explanation. During that period, 1931 to 1935, returns per acre from wheat averaged about six dollars, which may be compared with the period 1925 to 1928 of $18.50, or over three times the return per acre of the later period.

The reduction in returns per acre to less than one-third in the later period as compared with the previous years was due partly to yield per acre and partly to lower prices. In the early period the yield averaged 18.4 bushels and in the later period 12.9 bushels. In the first period the price at the farm averaged $1.01 per bushel, and in the later period 48 cents per bushel. The reduction in return per acre was 37 per cent due to yield and 63 per cent due to lower price.

Whatever was the cause, it is useless to expect farmers to be able to retain sufficient of the returns from prosperous periods to maintain purchasing power in bad times when the variation is as great as this record shows. Insurance against crop failure has been applied successfuly, but insurance against price declines is a more difficult matter. Perhaps it is not impossible.

Cause of the Price Decline

The cause or causes of the much greater fall in prices of farm products and the prevalence for almost exactly seven years of the great discrepancy between prices of farm products and some other goods cannot be omitted from this survey.

The prices of farm products fell farthest and stayed down longest because there were few artificial props to sustain them. The bargaining power of the purchasers of farm products was greater than was that of the vendors during this time. Why? On account of the artificial supports which stabilized some other prices. Two of these artificial supports must be mentioned.

First, we have the tariff, which expects the farmer to take world prices, to produce a surplus to secure world prices, and to exchange his products at world prices in the domestic market for goods some of which are provided him at a higher price on account of being provided in a protected domestic market. The result is that the farmer buys some of his raw materials in a protected market and is expected to sell his finished product in a free and open market.

Second, the bargaining power of the farmer is weak on account of bargaining individually. As compared with this condition, we have other industries using a greater or lesser degree of collective bargaining. As a result, farm wages were reduced, both in the depression of 1921 and the later one we are now discussing, to a much greater degree than wages in other lines of activity.

Wages

In 1910 yearly farm wages, including the value of board, amounted to 83 per cent of the yearly earnings in manufacturing. By 1915 the proportion was 67, in 1919 it was 83, and in 1922, it was 63 per cent. From 1930 to 1934 the proportion declined from 60 to 40 per cent. During the four years from 1931 to 1934 inclusive, the proportion averaged slightly less than 42 per cent.

There is no argument here that the proportion was desirable or the reverse in 1910 or in any other year. What is maintained is that the *trend* has been definitely and distinctly against agriculture. If the proportion was desirable in 1910, then it was decidedly out of line during these two depressions and particularly during the recent one.

Such a result indicates that there is some underlying cause. The cause is the lack of any degree of strength in bargaining power on the part of the farmer. The weak bargainer is unable to pass on overhead, such as taxation. The farmer would add such items to price, if possible, but without collective bargaining there is small chance of it. Therefore the prices of farm products fell first and farthest and stayed down longest on account of:

1. The farmer having limited financial power and unlimited liability—dealing with corporations directly organized to secure ample financial power and limited liability.
2. The farmer dealing individually and indirectly with labour in industry which uses collective bargaining power.
3. The farmer dealing individually with stronger groups had small chance of maintaining prices in order to pass on taxes or other increased costs to the consumer of his products.

One of the results of the great discrepancy between prices of farm products and those of other things was that the net return to agriculture for the country as a whole was cut down to much less than half of what it had been prior to the price decline. For the six years from 1931 to 1936 estimated net returns averaged $570 million; whereas in the six preceding years the average was over $1,300 million. The three-quarter of a million farms in Canada in 1931, employing one and one-eighth million workers and cropping 60 million acres besides pasturing some nine million acres, had an average of $570 million per year from farming. This net figure is arrived at by making deductions[4] from the value of all products for feed fed to live stock, seed and fruit and vegetables used in the home. The net figure is expected to provide payment for hired labour (valued at $100 million in 1930), payment for the entrepreneur—in this case the farmer and his family, who do the major portion of their own work—purchase equipment, keep up repairs and provide the return (if any) on the investment. It is clear that the term *net return* should not be taken too seriously in the light of these figures.

Another result has been that returns on investment in agriculture do not exact so great a share as formerly, and for the reason that the proportion

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[4] Monthly Bulletin Agr. Statistics, March Numbers.

of the national wealth invested in farming has recently grown smaller and still more beautifully less. Let the following records tell the tale.

PROPORTION OF NATIONAL WEALTH INVESTED IN AGRICULTURE

	1921†	(000)s 1929*	1933*
Total national wealth	$22,195,302	$31,275,814	$25,768,236
Total invested in Agriculture	7,982,871	7,939,477	5,563,790
Per cent of total	35.97	25 39	21.59
Value of urban real estate	5,751,505	8,251,011	6,913,530
Per cent of total	25 91	26 38	26.83

* Canada Year Book 1937, p. 862.

† Canada Year Book 1926, p. 803.

Since 1921 the proportion of the total national wealth credited to agriculture has declined from 36 to 22 per cent; hence 1921 investment in agriculture has declined two and a half billion in round numbers, while urban real estate has increased in value over one billion. Now urban real estate is more valuable than the total investment in agriculture, including the 160 odd million of acres now occupied as farm land. The marked reduction of the value of the agricultural plant has resulted in the practical disappearance of the credit of the industry. Hence another result of the past record is the disappearance of the customary sources of farm credit, formerly private capital. Provision of credit for carrying on farming has become more and more dependent on public funds provided by federal agencies.

SUMMARY AND SUGGESTIONS

Recent developments reveal that agriculture is not sufficiently prosperous to promote expansion. Under such conditions anticipation of expansion is hopeless. What is required is a new national policy—a national policy depending less on export of surplus farm products and more on forest and mineral products, where we have equally great advantage in natural resources and where foreign competition is less keen.

Of course there is an alternative method, namely, that of lessening the cost of production of farm products in order to enable a larger share of the world market in exports of farm products to be secured. Such a policy is unpopular with urban industry which is important in supplying equipment for farmers, transporting and processing farm products. Judging by the records examined, there is small chance of such a policy being followed. Hence the necessity of being contented with a smaller share of the world market for farm products and greater dependence on other exports.

Growing grain for export with the mechanized methods necessary to keep costs down does not offer much promise of employing many workers. On the other hand, turning surplus grain into meats and dairy products offers an opportunity not only of getting rid of surplus grain—when there is a surplus—but also employs more labour.

The greatest assistance to the wheat and grain grower would be the expansion of other industries that employ labour and increases the number of workers and the expansion of other lines of farming besides grain growing where dependence on world markets is not so great. Such a policy is advanced as a possible alternative to a bonus or minimum price set on a product that has been produced during the past few years below production costs and may again be in that category.

Further, there is both a guide and an opportunity of regulating or restricting the amount of wheat grown in Western Canada if and when the authorities wish to follow the guide and exercise the regulation. The guide to the advisability of sowing wheat is the amount of moisture stored in the subsoil the previous year. It is admitted that this guide is not infallible. Yet it is generally conceded that it is a fair criterion. The possibility of regulation or restriction comes from the present dependence on federal funds to provide seed. The stipulation that funds for seed would be supplied only to those whose land was well prepared might be used and will have to be resorted to when the public tires of furnishing funds for so risky a venture.

The expense of handling exportable surpluses of farm products, whether in the raw products of grain or in more concentrated forms such as meats, must be reduced. It is begging the question to argue that these expenses are now at a minimum. These expenses may be at a minimum if the present rates of wages are maintained in industry. On this basis a smaller share of the world market for farm products may be anticipated. If it be considered necessary or advisable to expand or even retain a share of the world market for farm products, some reorganization may be necessary in other industries than farming.

Finally, the taxation of the farmer must be lightened. No reference is here made to the income tax, which some farmers claim they would like to pay provided they had the income. And the reference is not restricted to the personal property tax, which degenerates into a real estate tax burdensome in many cases, but includes the indirect taxes, the incidence of which is so difficult to trace, but which are passed on in the price of the product by those who have the greater bargaining power.

EFFECTS OF SOME FIELD PLOT TREATMENTS ON DROUGHT SPOT AND CORKY CORE OF THE APPLE[1]

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[Received for publication November 6, 1937]

In the spring of 1931, a number of field plots were established in the Kelowna Project apple orchard, at Kelowna, British Columbia, for the purpose of studying the effects of various treatments on drought spot and corky core of the apple. As a result of this work, it has been found (3, 4) that both of these disorders are due primarily to a deficiency of boron. McLarty (3) has reported that when chemicals containing boron (such as boric acid and manganous borate) were injected into the trunks of the trees, both drought spot and corky core were completely eliminated in the following year's crop. McLarty, Wilcox and Woodbridge (4) have reported that applications of boric acid or of borax to the soil have also brought about complete control. Where the trees have not been treated with boron, however, the severity of the disorders has been influenced in one direction or the other by certain of the other field plot treatments. The results of these treatments are reported in this paper. In addition, there are presented certain correlations between the severity of drought spot and other tree characteristics.

DESCRIPTION OF ORCHARD

The orchard consists of 23 acres of apple trees, of the following varieties: McIntosh, Jonathan, Delicious, Newtown, Duchess and Wealthy. The permanent trees are 30 feet apart; and where fillers are present (in one plot), the trees are 21 feet apart. Most of the trees in the plots were 19 years old when the tests were started, though there were a number of younger trees where replantings had been made. Drought spot, corky core and their related disorders were quite prevalent in all of the experimental plots.

The soil throughout the plots is a sandy loam, ranging for the most part from 1 to 3 feet in depth, and is underlain by a mixture of coarse sand and gravel. In certain small areas, the gravel comes almost to the surface. The moisture holding capacity of the soil above the gravel averages about 16%. Except in those plots receiving fertilizers, the pH of the soil ranges from 6.8 to 7.1. Analyses made on samples collected from untreated plots showed the following concentrations of available nutrients, expressed as parts per million of dry soil:[3]

NO_3	1.31 to 15.60 p.p.m.
PO_4	1.74 to 11.50 p.p.m.
K	30.80 to 69.40 p.p.m.
Ca	12.80 to 33.10 p.p.m.
B	0.08 to 0.20 p.p.m.

[1] Contribution No. 485 from the Division of Horticulture, Experimental Farms System, Canada.

[2] Graduate Assistant in charge of the horticultural work of the Kelowna project.

[3] The soil samples were taken with an auger, down to the gravel. The solution for analysis was made by mixing one part by weight of soil with an amount of water equal to 25 times the moisture holding capacity. The mixture was saturated with CO_2 for 24 hours, then filtered through a Livingston atmometer. The analyses have been made by Mr. C. G. Woodbridge, chemist of the Physiological Disorders Investigation at Summerland.

Tests with HCl gave no evidence of free carbonates, either in the top soil or in the gravel below. The cover crop consisted at the start of the tests largely of alfalfa; but over the 6-year period the alfalfa has mostly died out and been replaced by grasses, weeds, and occasional patches of sweet clover.

Except for the differential plot treatments, uniform cultural practices have been maintained throughout the orchard. The cover crop has been disced once a year, in the spring. The irrigation furrows have been spaced 3 to 4 feet apart. Irrigation water has been applied every 10 to 12 days during some 4 months in the summer, with a 12-hour run at each application. The total amount of water thus applied has varied each year over the orchard as a whole from 30 to 52 acre inches per acre, depending on the season's requirements. In addition, the annual precipitation (mostly in the dormant season) has ranged from 10.2 to 15.4 inches during the 6-year period. Except in the fertilizer plots, no fertilizers have been applied. The pruning practised has been moderately light.

Over one-half of the orchard was divided into plots in the spring of 1931, and differential treatment was started on about two-thirds of them, the balance being retained as checks. The plots ranged in size from 0.2 to 0.5 acre, and the number of treated trees in each plot from 6 to 21. Between each pair of plots, a "buffer" row has been maintained, receiving on either side the respective plot treatments. For the most part, the plots have contained a sufficient number of trees of the same variety and of similar size and condition to warrant the drawing of conclusions from the results obtained, but in certain cases they have not. Special note will be made of such plots when their results are reported below.

RECORDS TAKEN

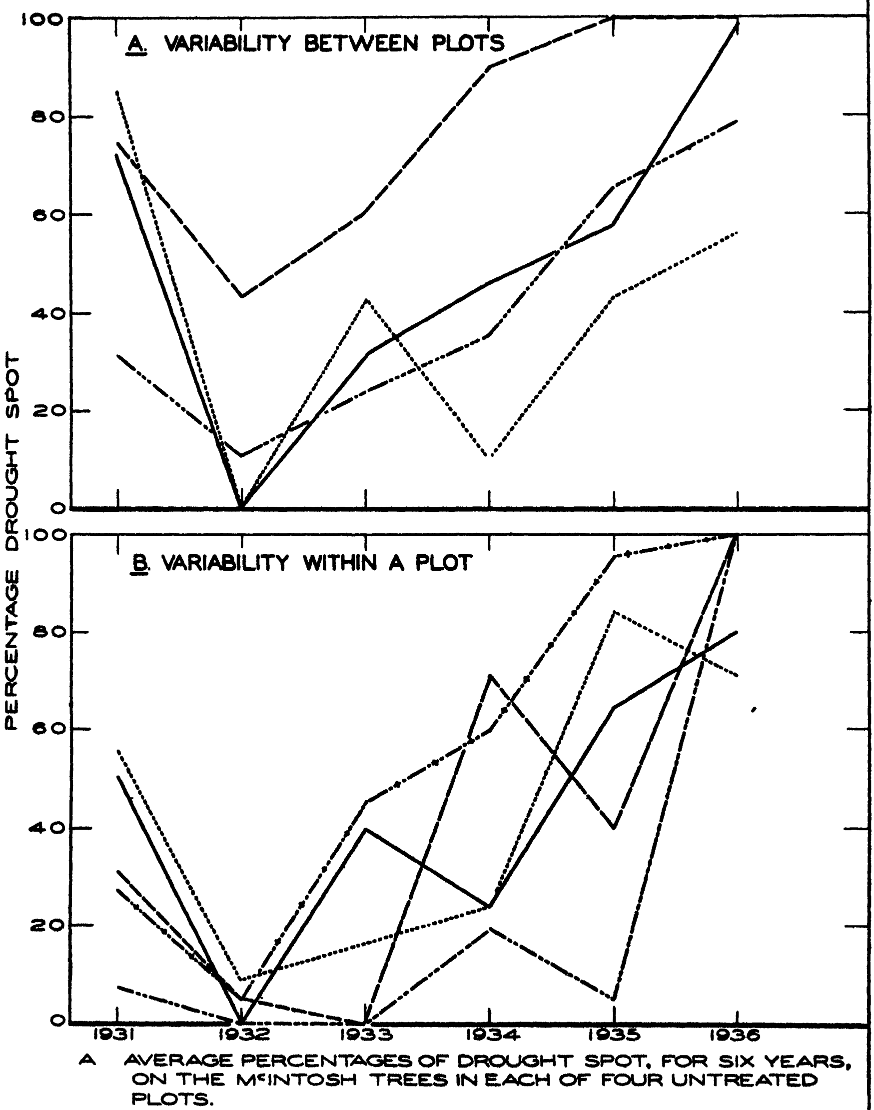
During the past 6 years, individual tree records have been taken on all of the plot trees. These records include the trunk circumference, terminal length, terminal diameter (up to 1934), percentage bloom, percentage set of fruit, crop of saleable fruit, percentage drought spot, and percentage corky core. In addition, notes have been taken on foliage condition, twig die-back, and various other characteristics of the trees. The methods of recording the growth, bloom, and fruiting have been described by the author in previous publications (5, 6), and will not be repeated here. The percentages of drought spot and corky core have been recorded at picking time, the procedure used being as follows: Each tree was divided into quarters, in accordance with the points of the compass. From the ground, 10 apples were selected at random from each quarter of the tree, and 10 more were selected from the top centre, making a total of 50. The number in this 50 that showed drought spot were counted. They were then cut and the number showing corky core were counted. The figures thus obtained have been multiplied by 2 to give the respective percentages.

PLOT TREATMENTS AND RESULTS

Check Plots

The untreated plots are used throughout this report as a basis on which to judge the effects of the differential plot treatments. The variability between and within these plots is accordingly of great importance.

By way of illustrating the variation between plots, the average percentage drought spot in each of four check plots containing McIntosh trees is charted in Figure 1A. The average is, in each case, that of the McIntosh trees only. In Figure 1B is charted the percentage drought spot on each of five McIntosh trees in one untreated plot. It will be seen that there has been a good deal of variability both between and within plots. These charts also illustrate the general tendency of the percentage drought spot



A AVERAGE PERCENTAGES OF DROUGHT SPOT, FOR SIX YEARS, ON THE McINTOSH TREES IN EACH OF FOUR UNTREATED PLOTS.

B. PERCENTAGES OF DROUGHT SPOT ON EACH OF FIVE McINTOSH TREES IN ONE UNTREATED PLOT.

FIGURE 1. An illustration of the variability in percentage drought spot, both between plots and within a plot.

in the orchard as a whole to drop very low in 1932, and to rise fairly steadily again each year since that time. The corky core tendencies have been very similar to those of drought spot. It is evident from these results that good commercial care, as applied to the check plots, has not served to cure drought spot or corky core.

Variation in Water Supply

In his preliminary work on drought spot and corky core, McLarty (1, 2) found that these disorders could be influenced a great deal by the moisture conditions in the soil. His findings have accordingly been followed up by a number of treatments designed to test various methods of irrigation, including not only a variation in the total amounts of water applied during the season, but also a variation in the amount per irrigation with the total during the season kept constant. These treatments have been applied to three series of plots. In the first series (4 plots) a total of 32.5 inches in depth of water (32.5 acre inches per acre) has been applied during the season to each plot, while the time between irrigations has been arbitrarily set at 5, 10, 15, and 20 days in the respective plots. The amount of water applied at each irrigation has been 1.33, 2 67, 4 00 and 5.33 inches respectively. In the second series (3 plots), the soil has been wetted to the gravel every 5, 10, and 15 days respectively. In the third series (4 plots), one plot has been irrigated to the gravel every 10 days, and after each application the depth of water applied has been calculated and the other three plots given $\frac{1}{4}$, $\frac{1}{2}$ and twice that depth respectively. In each of these 11 plots, the water has been measured with a miner's inch box devised by Mr. R. C. Palmer of the Dominion Experimental Station at Summerland, and has been carried along the top of the plot in a small secondary flume, as illustrated in Figure 2.

In the first two of these plot series, the results on the individual plots have not shown sufficient differences in the trends of drought spot or corky

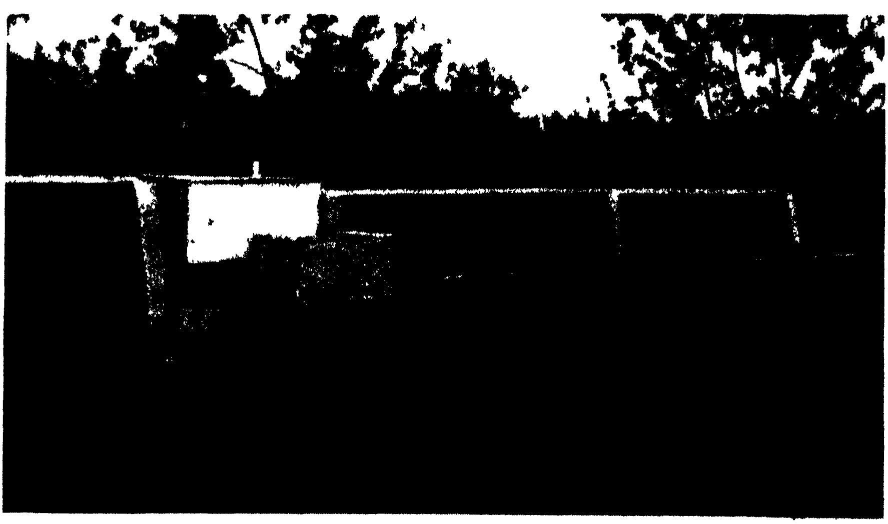


FIGURE 2. Method of measuring the water and distributing it on each of the special "water plots".

core to justify any conclusions. Any differential effects that there may have been as a result of the variations given in the water supply have been hidden by the strong tendency (since 1932) of all the plots to increase in drought spot and corky core. In the third series, however, the differences have been quite marked. In the two plots receiving the lesser quantities of water, severe wilting has occurred, the growth has been poor, the fruit has been small, drought spot has been severe, and corky core has been especially severe. Wilting of the trees early in the season has in all cases been followed by severe corky core the same year, both in these two plots and in other sections of the orchard On the other hand, doubling the supply of water over that necessary to wet the soil has made little difference in either drought spot or corky core. Owing to the gravelly nature of the subsoil, the excess water in this plot has readily drained away. In none of the water plots has the pH of the soil shown any material change, being in 1936 still within the range 6 8 to 7 1.

The drought spot trends are illustrated in Figure 4A, and the corky core trends in Figure 4B. At the bottom of the chart is shown the number of trees used in constructing each line of trend. Restriction of the data used to those of the one variety lessens considerably the number of trees entering into each average, but gives a truer picture of the trends than where all the trees in the plot are averaged. In each case, the other varieties have shown the same trends, though the percentages of drought spot or corky core have been either higher or lower than those of the variety used. The same holds true of the other charts to follow. The general effects of a water deficiency on tree growth and die back are illustrated in Figure 3.

Application of Commercial Fertilizers

Before the start of this experimental work in 1931, a good deal of evidence had been obtained in the Okanagan Valley to the effect that drought spot and corky core could be influenced by stable manure and by com-

FIGURE 3. Type of growth induced by a deficiency of water, on trees subject to a drought spot condition.

mercial fertilizers. McLarty (1) reported in 1927 that manure had increased the severity of corky core. Observations in grower-owned orchards had likewise indicated that in some cases nitrogen had had a deleterious effect, and potash a beneficial effect. Separate tests of the three primary fertilizing materials had however not been conducted in any systematic manner. It was accordingly decided to lay out 4 series of plots, to be treated with nitrogen, phosphate, potash and mixed fertilizers respectively. These materials have all been applied annually, in the spring before the

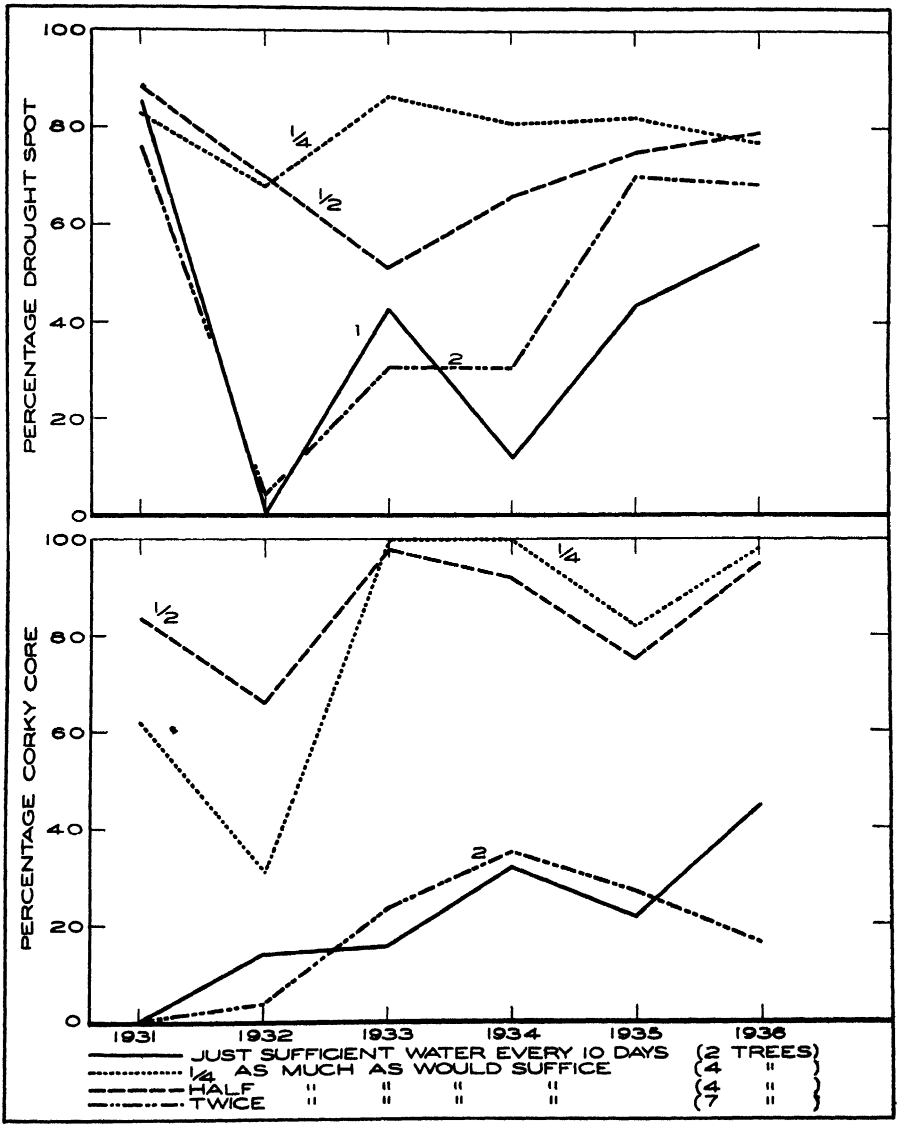


FIGURE 4. Effects on drought spot and corky core of a deficiency of water. McIntosh trees only.

start of the first irrigation. They have been spread evenly over the surface of the ground from near the trunk out to or just beyond the outermost spread of the limbs.

Nitrogen has been applied in the form of sulphate of ammonia, at annual rates of 6 pounds per tree in one plot and 15 pounds in a second plot. Both rates of application have increased the vigour of the trees markedly, and have also increased the severity of the drought spot. The trees are all of the Delicious variety, which seldom exhibits any corky core and which is not usually as severely affected by drought spot as is the McIntosh or Jonathan. The drought spot trends are shown in Figure 5. The moderate applications of nitrogen have acidified the soil to an average of pH 6.3, and the heavy applications to an average of pH 5.2.

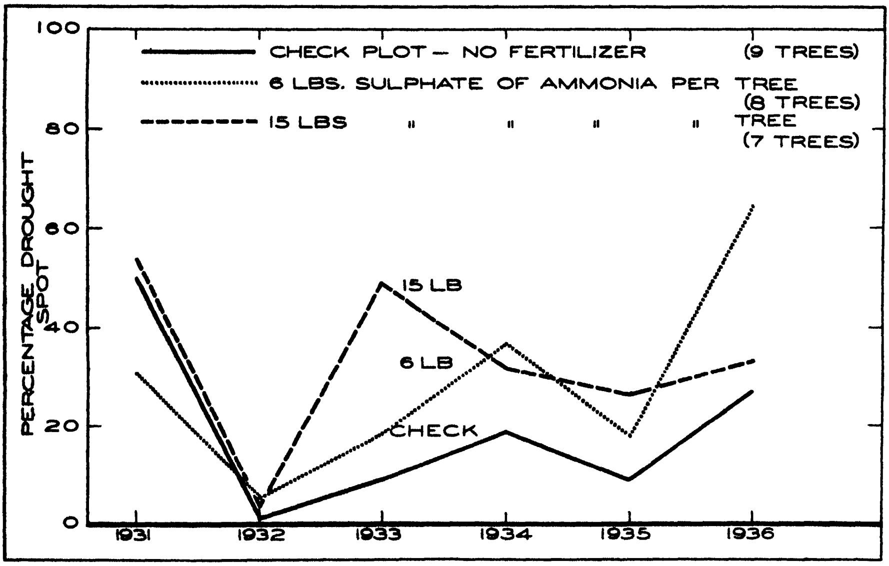


FIGURE 5. Effects of annual applications of sulphate of ammonia on percentage drought spot. Delicious.

Phosphate has been applied in the form of ordinary superphosphate, at annual rates of 4 pounds and 20 pounds per tree in two respective plots. The trees have been mostly Jonathan, with some McIntosh. In both of the treated plots, drought spot and corky core have been especially severe. However, the soil is somewhat shallower than in the check plots, so that it is questionable just how much of the results can be attributed to treatment. It will be seen in Figure 6 that the 4-pound plot was worse at the start than were the other 2 plots. The soil has been rendered slightly more acid by the superphosphate (pH 6.6 to 6.8).

Potash has been applied in the form of muriate of potash, in one series at annual rates of 2 pounds and 20 pounds per tree in 2 respective plots, and in a second series at rates of 10 pounds and 20 pounds per tree. In the first series of plots, the trees are all Delicious. In this series, the heavy applications have been accompanied by quite definite decreases in percentage drought spot. Since however the soil in the 20-pound plot is a

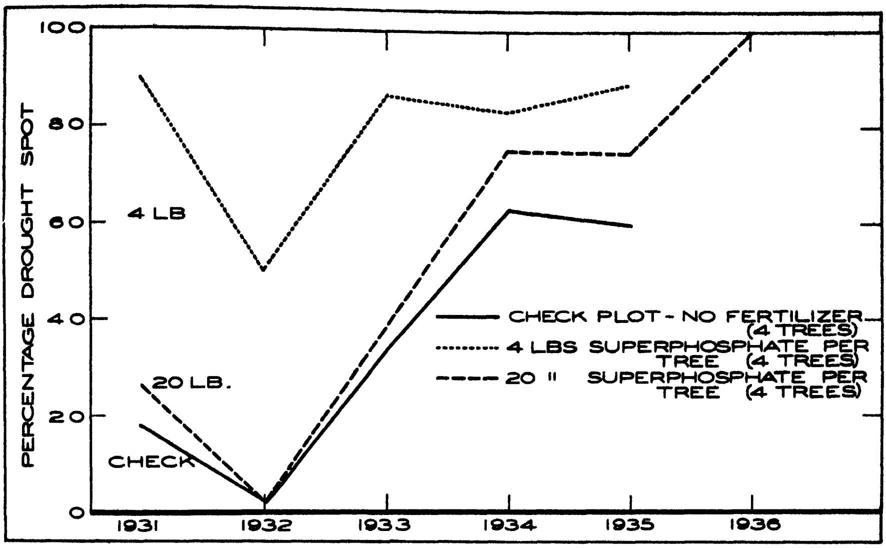


FIGURE 6. Effects of annual applications of superphosphate on percentage drought spot. Jonathan trees only. Treatment on two of the plots was discontinued in 1936.

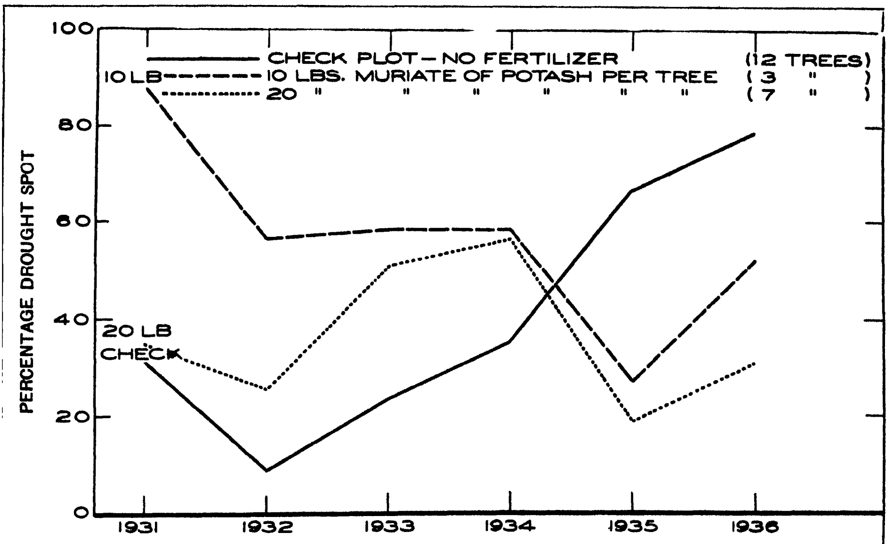


FIGURE 7. Effects of annual applications of muriate of potash on percentage drought spot. Treatment started in 1934. McIntosh trees only.

little deeper than in the other 2 plots, the results may not all be attributable to treatment. The second series, in which the trees are McIntosh and Jonathan, was not started until 1934. In the 2 treated plots, there was a drop in percentage corky core in 1934, and a drop in percentage drought spot in 1935. The drought spot trends in this series are shown in Figure 7. There has been no apparent effect of the treatment on the pH of the soil.

It might be noted that the muriate of potash used in this work has been found to contain 0.03% B_2O_3 as an impurity.[5]

Two different mixtures of fertilizers have been applied in two separate plots. In the first plot the annual rates of application have been 6, 4, and 2 pounds respectively of the three fertilizers, giving 12 pounds per tree of a 10-5-8 ratio. In the second plot, the rates have been 15, 20, and 20 pounds respectively, giving 55 pounds per tree of a 5-6-18 ratio. The trees in this series are Jonathan and McIntosh. The 10-5-8 fertilizer has increased vigour markedly, but appears to have had little effect on drought spot or corky core. The 5-6-18 fertilizer has likewise increased tree vigour. It produced at first a definite improvement in drought spot and corky core; but by 1935 there was once again as much of each showing as in the check plot. The trees in all three plots were treated with boron in 1936, and the drought spot was thus eliminated. The pH of the soil has been lowered to around 6.0 in the 10-5-8 plot, and to around 5.0 in the 5-6-18 plot.

Pruning, Root Pruning, Tree Crowding

When the field plot tests were being laid out, it was thought that the ratio of top to root might influence drought spot and its related disorders, through the effect of this ratio on the balance between the requirements and the supplies of water and nutrients. Accordingly, treatments were initiated such as to change this ratio from the normal. These treatments included pruning of the top, pruning of the roots, and crowding of the trees, with the respective objects of reducing the top, reducing the roots, and preventing the free growth of both top and roots.

Three plots have been pruned with different degrees of severity: no pruning, moderate pruning, and severe pruning. No pruning has been accompanied by a lessened growth of shoot and trunk. Severe pruning, *i.e.*, the removal of about 25% of the wood and buds each year, has induced more twig growth for 2 years only: since 1932, neither the growth of the shoots nor that of the trunk has been any greater than with moderate pruning. Neither extreme of pruning has had any apparent effect on drought spot or corky core. All three of the pruning plots were severely affected with drought spot and corky core at the start of the experiments in 1931.

Six trees were root-pruned in the spring of 1931, by digging trenches around them down to the gravel: 2 at 4 feet from the trunk, 2 at 7 feet from the trunk and 2 at 10 feet from the trunk. Growth and production have been lessened in all cases, especially with the more severe treatments. There appears however to have been little if any effect on drought spot or corky core. A similar result has been noted where trees have been affected by crown rot or bad sunscald, *i.e.*, a lessening of vigour with little change in drought spot or corky core.

In a series of two adjacent plots, the filler trees were removed from one in the spring of 1931, but left in the other. The crowding of the trees in the latter plot has been accompanied both by a lowering of vigour and by a decrease in severity of drought spot and corky core, in comparison with the other plot.

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[5] Analysis by Mr. C. G. Woodbridge

DROUGHT SPOT CORRELATIONS

By the use of dot diagrams and coefficients of correlation, studies have been made each year of the relationship between drought spot and each of the measurements representing tree growth and fruiting. The methods of making the correlations have been outlined by the writer in a previous paper (6). The trees used for these studies have been those in the untreated plots that have been affected with drought spot.

The coefficients of correlation between drought spot and either growth or fruiting have for the most part shown good uniformity in sign and significance from year to year. An exception was in 1932, when for some reason the percentage drought spot dropped so low that the correlations were not statistically significant. For the sake of brevity, the correlations reported at this time are being confined mainly to 2 years, 1934 and 1935, and to one variety, the McIntosh. They have been calculated from the field records on 50 trees of bearing age. In the results presented below, a coefficient of correlation is considered to be statistically "significant" when the odds are between 19 : 1 and 99 : 1, and "highly significant" when they are over 99 : 1.

Drought Spot in Successive Years

The coefficient of correlation between the percentage drought spot in 1935 and that in 1934 was +0.353, which is statistically "significant".

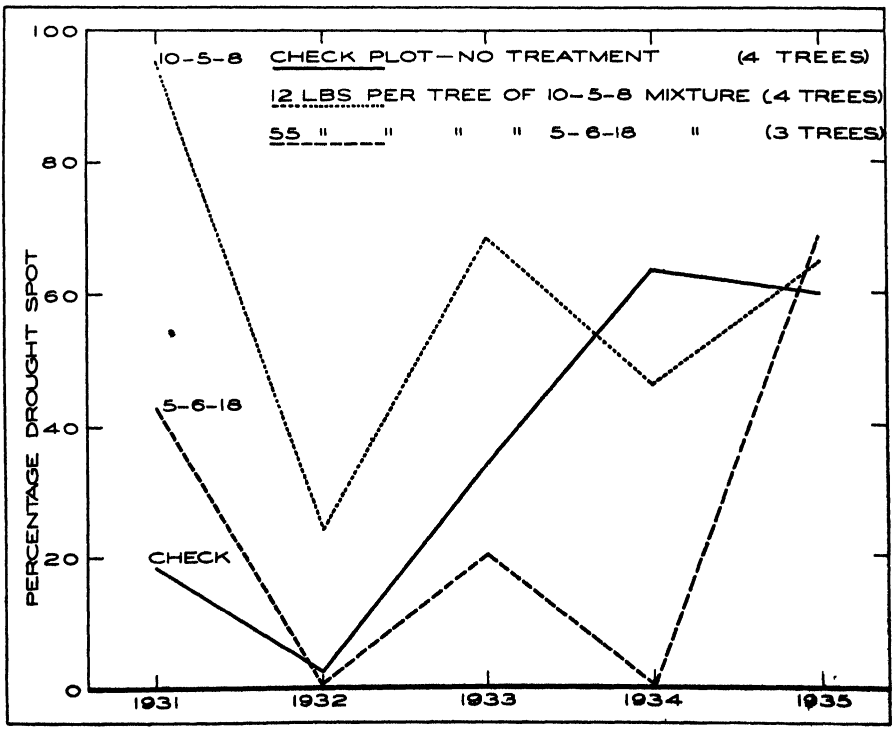

FIGURE 8. Effects of mixed fertilizers on percentage drought spot. Jonathan trees only. Treatment was discontinued in 1936.

This is an indication that in spite of all other factors that may have affected the drought spot, the disease has tended to be more severe in successive years on one tree than it has on another tree. The coefficient of correlation between the percentage drought spot in 1935 and that in 1933 was +0.501, which is "highly significant". This means that on the same tree, the disease has tended to be of the same degree of severity in alternate years more than it has even in successive years.

Drought Spot and Bloom

In order to study the relationship between the percentage drought spot and the percentage bloom in any one year, it has been found necessary to eliminate the general differences between trees in their susceptibility to drought spot and in their tendency to blossom heavily. This has been done in several ways, the most useful of which has been the "ratio" method described in a previous paper (6). When the percentage drought spot in 1935 was divided by that in 1934, and the same done with the percentage bloom, the coefficient of correlation between the 2 ratios thus obtained was −0.644. Substituting percentage set for percentage bloom gave a correlation of −0.586. Both of these coefficients are "highly significant". The indication is that there has been a very strong tendency for the fruit to be more severely affected with drought spot in the off year than in the on year, an indication borne out by general observation throughout a large number of orchards. This helps to explain the greater correlation noted above between drought spot in alternate years than in successive years. It also helps to explain the variation in percentage drought spot from year to year, as depicted in the plot tendency charts above.

Drought Spot and Tree Vigour

As just noted, biennial bearing has been found to have an effect on the percentage drought spot; and as previously reported by the author (6), it has likewise been found to have an effect on tree vigour. Thus in any study of the relationship between general tree vigour and susceptibility to drought spot, it is necessary to eliminate the effects of biennial bearing. This may be done by averaging the data for 2 or for 4 years. The following correlations have been obtained by averaging the McIntosh results for 1934 and 1935:

Coefficient of correlation between percentage drought spot and increase in trunk circumference	+0.340
Coefficient of correlation between percentage drought spot and terminal length	+0.432
Coefficient of correlation between percentage drought spot and growth index (increase in trunk circumference multiplied by terminal length[6])	+0.575

The first of these is "significant", and the second and third "highly significant". This means that the more vigorous trees have tended to be more severely affected with drought spot than have the less vigorous trees. It might be noted that although the trees used in these correlations have not been fertilized for at least ten years, they have been subject to wide variations in the proportion of legumes growing in the cover crop, which has been one of the primary factors influencing their degree of vigour.

[6] The use of the "growth index" has previously been reported upon by the author (7).

EFFECTS OF PLOT TREATMENTS ON THE RELATIONSHIP BETWEEN DROUGHT SPOT AND TREE VIGOUR

It was noted above that some plot treatments have been followed by an increase in drought spot, some by a decrease, some by neither. The same has held true with tree vigour. The effects on drought spot and vigour have, however, not been of the same type or of the same degree under the different treatments. In view of the high correlation between

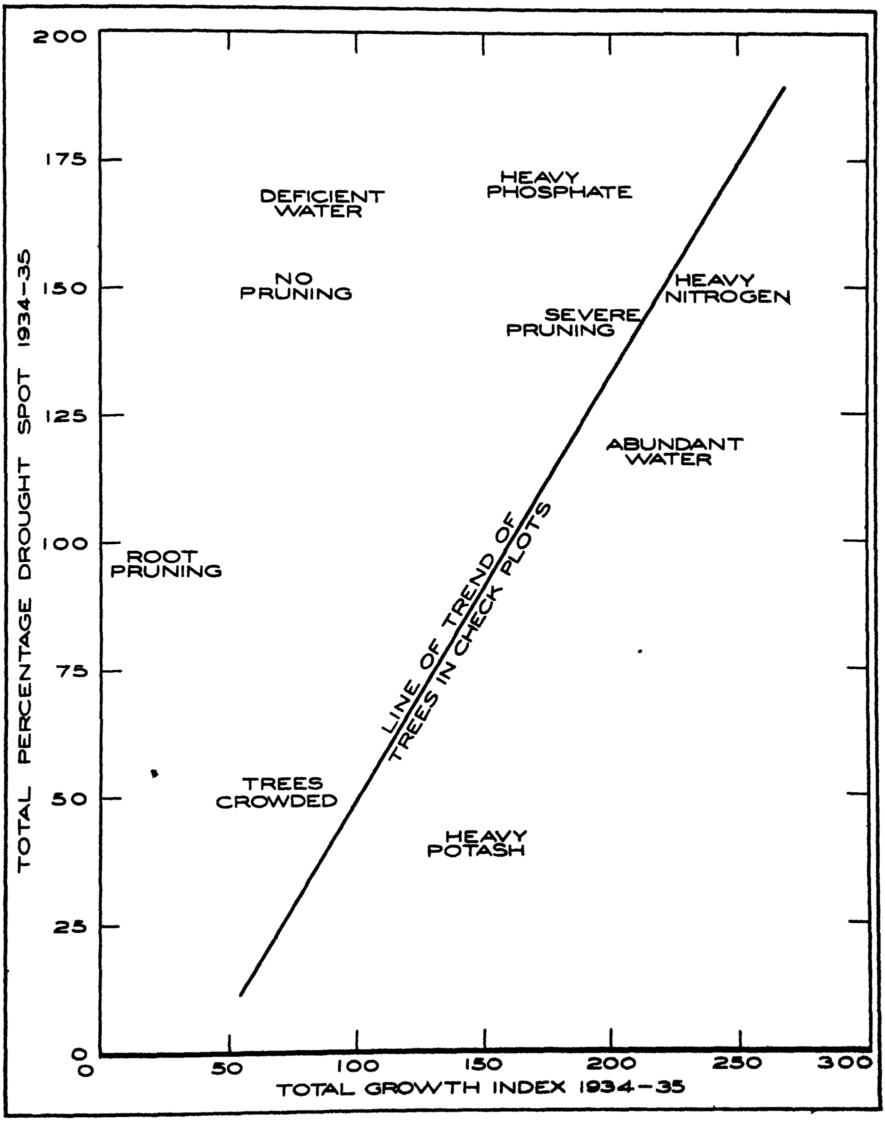

FIGURE 9. Effects of various treatments on the balance between percentage drought spot and tree vigour. The points designated represent the general positions of the McIntosh trees in the respective plots. The "heavy nitrogen" point has been estimated from its position on the Delicious charts. The "heavy potash" point is for 1935 only, multiplied by 2.

percentage drought spot and degree of vigour in the untreated plots, these differential effects of plot treatment attain considerable significance.

The method that has been used to study the effects of plot treatment on the relationship between drought spot and vigour has been, first, to chart the line of trend of the distribution obtained by plotting the one against the other in check plots, and then to note the general position of the plotted point for each tree in the treated plots. It can thus be determined whether any specific treatment has upset the normal relationship between drought spot and vigour as found in the check plots. By way of illustration, the line of trend for the McIntosh trees in the check plots during the two years 1934 and 1935 is shown in Figure 9. The total growth index for the two years is here used to represent general tree vigour. There is also shown the general position in the chart of the McIntosh trees in each of several of the treated plots. The number of trees used in determining these positions is the same as noted for the line graphs in Figures 4 to 7. The point marked "trees crowded" is for the plot where the filler trees were left in. Only two McIntosh trees were available to determine this position; however, the Jonathan trees in the plot assume the same general position in the Jonathan chart. The "heavy nitrogen" point has been estimated from its position in the Delicious charts. Since treatment in the "heavy potash" plot used was not started until 1934, the point shown was obtained by multiplying the 1935 results by 2.

An examination of the chart shows 3 general groups of treatments: (1) Those that have not changed the "normal" relationship between drought spot and vigour to any great extent. Heavy nitrogen, severe pruning, and crowding of the trees come in this category. The first has been accompanied by an increase in both drought spot and vigour. The second has had little effect on either, after 4 years of treatment. The third has been accompanied by decreases in both drought spot and vigour. It might be noted again that the trees in both the no-pruning and heavy-pruning plots showed severe drought spot at the start (*i.e.* in 1931). (2) Those that lie below the line of trend. An abundance of water appears to have increased the vigour somewhat, but has had little effect on drought spot. Heavy potash has decreased the drought spot without having had any apparent effect on vigour. (3) Those that lie above the line of trend. A deficiency of water has increased the drought spot and decreased the vigour. No pruning has decreased the vigour but has had little effect on drought spot. Heavy phosphate has had little effect on vigour, but has been accompanied by a high percentage of drought spot. As already noted, the soil is very shallow in this plot, and the results may not all be due to treatment. Root pruning has decreased the vigour markedly, but has had little effect on drought spot.

DISCUSSION

It has been shown by McLarty (3), and by McLarty, Wilcox, and Woodbridge (4), that drought spot and corky core as they occur in the interior of British Columbia can be readily controlled by treating with compounds of boron. There appears to be no doubt, accordingly, that a deficiency of boron is at the root of the trouble. This however does not preclude the possibility of other factors than the supply of boron having some influence on the severity of the disease. The results reported in this

paper do indeed point to such a possibility, for a number of the plot treatments have been accompanied by definite responses one way or the other in the severity of both drought spot and corky core.

It is not proposed at this time to attempt any explanation of the function of boron in the plant, or of its possible relationship to the above results. Some comment may however be made on the positive correlation between drought spot and vigour, and the apparent place of nitrogen in this relationship. An increase in the nitrogen supply, whether in the form of sulphate of ammonia or leguminous cover crops, has been accompanied by both increased vigour and a higher percentage of drought spot, in full accord with the balance found in the more vigorous trees in the check plots. Crowding of the trees, likewise, has lessened both vigour and drought spot, presumably through its effect on soil conditions. On the other hand, any decrease in vigour by other means than through the soil (*e.g.* no top pruning, severe root pruning, sunscald) has not been accompanied by a corresponding decrease in drought spot. It would thus appear that under the conditions encountered in these tests, the severity of the drought spot has been associated not merely with tree vigour as such, but rather more specifically with the supply of nitrogen.

Some comment should also be made on the partially beneficial effects of potash. As already noted, the muriate of potash used in this work has been found to contain very small amounts of boron as an impurity. It is just possible that this may explain the results obtained. McLarty (3) was unable to cure drought spot or corky core by the injection of potassium salts into the trunks of the trees.

A note of caution should be sounded with regard to the general application of the findings reported in this paper: the experimental results and the correlations are from trees which have all been affected in some degree by drought spot and its related disorders, and they cannot be applied to trees that have never been thus affected. Many orchards in the interior of British Columbia, for instance, have been dosed heavily with nitrogen without their showing any evidence of drought spot or corky core; while on the other hand, many orchards in a low state of vigour have been severely affected with both types of the disorder. However, in orchards where a tendency towards these disorders has been noted, an application of nitrogen or a deficiency of water has almost invariably been found to increase their severity.

SUMMARY

A large number of field plot treatments were initiated in the spring of 1931, in an attempt to find a cure for drought spot and corky core of the apple. These treatments have been continued for six years. Comparisons in the trends of drought spot have been made by the use of line graphs. Correlation studies have been made in the check (untreated) plots between drought spot on the one hand and amount of bloom and tree vigour on the other hand. The results reported are as follows:

1. A deficiency of irrigation water has decreased tree vigour, increased drought spot, and increased corky core markedly.

2. Fertilizer applications in heavy amounts (15 to 20 pounds per tree annually) have had both detrimental and beneficial effects. Sulphate of ammonia has induced both a more vigorous growth and more severe

drought spot. Superphosphate has had little effect on tree vigour, but appears to have increased drought spot somewhat. Muriate of potash has had no apparent effect on tree vigour, but has lessened the severity of the drought spot.

3. Severe pruning has increased tree vigour only temporarily. No pruning has decreased tree vigour markedly. Root pruning has decreased tree vigour even more so. None of these three treatments has had any measurable effect on drought spot. Tree crowding has lessened both vigour and drought spot.

4. Statistically significant negative correlations have been found between drought spot and percentage bloom, and positive correlations between drought spot and tree vigour. It is suggested that this last is due more specifically to the influence of nitrogen.

ACKNOWLEDGMENTS

The author wishes to express his indebtedness to Dr. H. R. McLarty, of the Dominion Laboratory of Plant Pathology at Summerland, who as officer in charge of the Physiological Disorders Investigation drew up the plans for these experiments, and who has assisted materially in the preparation of this report; and to Mr. R. C. Palmer, Superintendent of the Dominion Experimental Station at Summerland, for his guidance in the taking of the records and for his many helpful suggestions throughout the course of the work. Mr. M. S. Middleton, Mr. B. Hoy, and Mr. R. P. Murray, members with Dr. McLarty and Mr. Palmer of the Okanagan Physiological Disorders Committee, have also offered many valuable suggestions. In addition, the author wishes to acknowledge the assistance of Mr. C. G. Woodbridge, Chemist of the Physiological Disorders Investigation, in making the chemical analyses reported in this paper.

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PHYSIOLOGY OF APPLES IN ARTIFICIAL ATMOSPHERES[1]

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[Received for publication June 30, 1937]

INTRODUCTION

The influence of artificial atmospheres upon stored fruits has been the subject of much investigation during the past decade, not only in relation to the practical problems but also to those of a more fundamental character concerned with the living activities of the plant. The notable work of Kidd and West (20) has seen its fruition in the present commercial development of gas storage for apples, and their studies together with those of Blackman and others (3, 14, 32, 37) have greatly contributed to the knowledge of the process of plant respiration.

This report includes the following considerations:

1. Respiration.
2. Biochemical changes.
3. Osmotic and permeability relationships.
4. Fungal activity.
5. Physiological disorders.

The results of the above investigations will be dealt with under separate headings.

MATERIALS AND METHODS

Storage Methods

Three varieties of apples were used throughout the main experiments; namely, McIntosh, Cox Grange and Golden Russet. The fruit was first placed in storage at 0° C. immediately after picking, and then removed to cellar storage conditions at a mean temperature of 4.5° C. at the end of October 1935. At this time samples of fifty apples for each treatment were placed in five-gallon cans equipped with two copper tubes, one of which extended to the bottom of the container; these were used for sampling purposes. The lids of the cans were heavily vaselined and thus rendered gas tight. Carbon dioxide and nitrogen were added directly from cylinders under pressure, the latter being used to reduce the normal concentration of oxygen. An Orsat gas analysis apparatus accurate within 0.2% was used for the analysis of the atmospheres. Analyses of the atmospheres were made daily and the containers ventilated in order to maintain the desired concentration of carbon dioxide. At the end of December 1935, the material was moved from the Kentville Experimental Station, N.S., to a storage cellar at Macdonald College, Quebec, where the temperature averaged 3° C. (±1°).

[1] In partial fulfilment of the requirements for the degree of M.Sc.
[2] Graduate Assistant.

The treatments and controls in air which were used are shown in the adjoining table.

Variety	Per cent CO_2	Per cent O_2	Per cent N_2	Average gas concentration during entire storage period	
McIntosh	2.5	18.5	79	2 6 CO_2	
McIntosh	5 0	16.0	79	4.5 CO_2	
McIntosh	10.0	11.0	79	9.1 CO_2	
					Duplicate
Cox Orange	—	2.5	97.5	2.1 O_2	2.5 O_2
Cox Orange	2 5	18.5	79	2.4 CO_2	3.1 CO_2
Cox Orange	5.0	16.0	79	4.8 CO_2	5.2 CO_2
Cox Orange	10.0	11.0	79	9.5 CO_2	9.6 CO_2
Golden Russet	5 0	16.0	79	4.0 CO_2	
Golden Russet	10.0	11.0	79	9.2 CO_2	

Two examinations were made, 25 apples being used in each case. In the first examination 10 fruits were frozen at $-15°$ F. and the tissue ground up and stored in bottles for one week in the frozen condition until used for subsequent experiments. Another 10 fruits were set aside for acid, hydrogen ion concentration, and refractometric determinations.

In addition, several subsidiary experiments were undertaken in which the concentrations of carbon dioxide and nitrogen were adjusted to high levels for limited periods.

Respiration

The evolution of carbon dioxide from the fruit was measured by means of the weighed tube method, the equipment and methods being similar to that described by the author in a previous paper (10) with some modifications. The carbon dioxide absorbent, "Ascarite", a Central Scientific Company product, was substituted for the soda flake. This absorbent is the American equivalent of the B.D.H. product, "Carbosorb", both of which are used extensively in organic analysis. Figure 1 indicates the

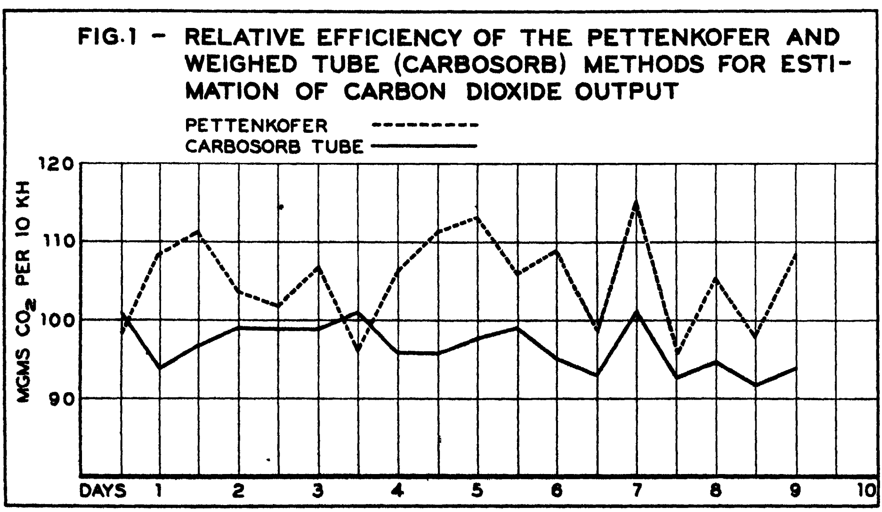

FIGURE 1. Relative carbon dioxide absorption by the weighed tube and Pettenkoffer methods for respiration measurements at 10° C.

relative efficiency of "Carbosorb" as compared with the Standard Pettenkofer method in which the carbon dioxide is absorbed by barium hydroxide. A small "Marco" pump was used to drive the air through the system.

The incoming air was passed through a large tube of soda lime and conditioned to a relative humidity of 75% by bubbling through a solution of 30% potassium hydroxide. After passing over the fruit the air was dried by means of two tubes of coarse- and fine-mesh calcium chloride respectively. A flask containing a weak solution of sodium hydroxide plus methyl orange was placed at the end of the train in order to detect improper absorption and to check the speed of the air flow (2 litres per hour). The entire apparatus is shown in Figure 2.

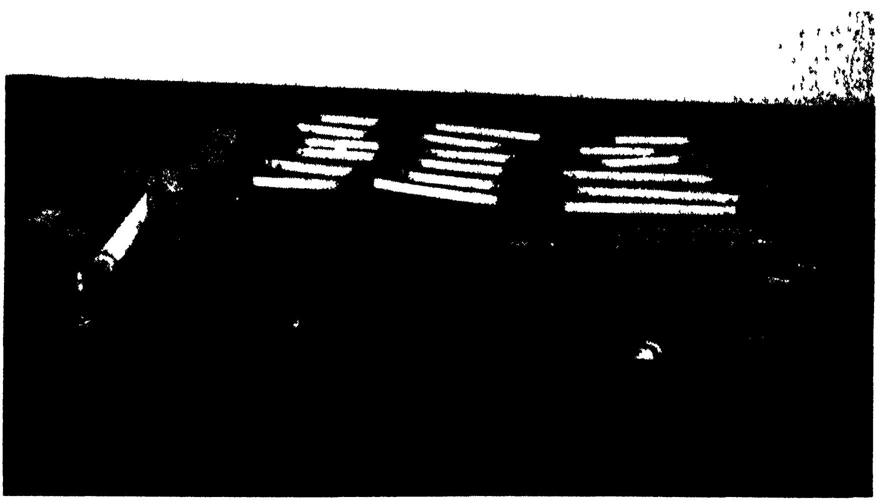

FIGURE 2. Apparatus for the estimation of carbon dioxide output of apples.

Estimations of the carbon dioxide output and oxygen uptake of fruit in the five-gallon containers were made by means of the Orsat apparatus.

RESULTS

Respiration

The measurement of the respiratory activity of fruit stored at low temperatures by means of gas analysis was considered to be unsatisfactory owing to the very slow rate of carbon dioxide output obtained under such conditions (see Figure 6). The first experiment, using the gas analysis method, was therefore carried out at 21° C.

The object of this experiment was to ascertain the effect of artificial atmospheres upon apples belonging to the Stark variety which had been stored in air at 3° C. for approximately four months. Samples of fruit, each weighing 2240 grams, were removed from storage and placed in containers the lids of which were sealed very thoroughly with a layer of vaseline 0.25 inch in thickness.

This method of obtaining a record of carbon dioxide is relatively crude when compared with the Pettenkofer or weighed tube method. Never-

theless it was felt that the use of such large samples, approximately 30 apples, would serve to minimize the error obtained by using single fruits. Care was taken to avoid upsetting the internal atmospheres, particularly the high carbon dioxide container, in which a negative pressure was developed at the time of analysis. In view of these reservations attention was given only to total carbon dioxide output and oxygen consumption over the period stated.

Four treatments were used and the changes in the atmospheres noted after 5 days. The containers were then thoroughly aerated and closed again for a further 4 days. Table 1 indicates the atmospheric changes found under these conditions.

TABLE 1.—CARBON DIOXIDE OUTPUT AND OXYGEN UPTAKE OF STARK APPLES AT 21° C. IN DIFFERENT ATMOSPHERES (PER CENT DECREASE AND INCREASE IN CONTAINERS)

Treatment	In artificial atmosphere (5 days)		In air (4 days)		Respiratory quotient in air	
	CO_2 increase	O_2 decrease	CO_2 increase	O_2 decrease	Initial	Final
(1) 6.2% CO_2	14.3	11.0	10 7	7.9	1 66	1.08
(2) 53.5% CO_2	9.0	7.0	17.5	10.7	2 14	1.00
(3) 99.0% N_2	15.3	1.0	11.3	6.6	1.66	1 15
(4) Control in air	11.7	8.2	9.4	7.0	1.60	1.20

It will be seen that the total carbon dioxide output from fruits placed in high concentrations of carbon dioxide is less than that shown by the controls, but that upon removal to air the relationship is reversed as seen by the initial respiratory quotient in air of 2.14. This is followed by a sharp readjustment to an R. Q. of unity which would indicate an initial expulsion of carbon dioxide from the tissues.

On the other hand low carbon dioxide (6.2%) and nitrogen (99.0%) treatments are characterized by a greater increase in carbon dioxide output than the control which is also maintained upon removal to air. The oxygen consumption of these lots when removed to air differs in that the uptake of nitrogen-treated apples is lower than either the low carbon dioxide treatment or the controls. It may be further noted that the oxygen consumption of the high carbon dioxide treatment when removed to air is much in excess of the other lots.

Samples of McIntosh apples were also carried under similar conditions, but trouble was experienced with pressure differences when the containers were removed from cold storage to ordinary room temperatures. Nevertheless, both the Stark and McIntosh apples placed in nitrogen were characterized by a disappearance of the red pigmentation. This development, which to the writer's knowledge has not been reported before, is shown in Figure 3. The effect rather resembles soft scald when photographed, but is quite different in that the decolorized areas are almost white in appearance as distinguished from the sharply delimited light brown patches which are seen on scalded apples.

FIGURE 3 Loss of red pigmentation in senescent McIntosh apples stored in 100% nitrogen at 21° C

The relative respiration rates of Golden Russet apples stored at 3° C. and 21° C., as determined by the weighed tube method, are shown in Figure 4, but the differences due to treatment with carbon dioxide are not

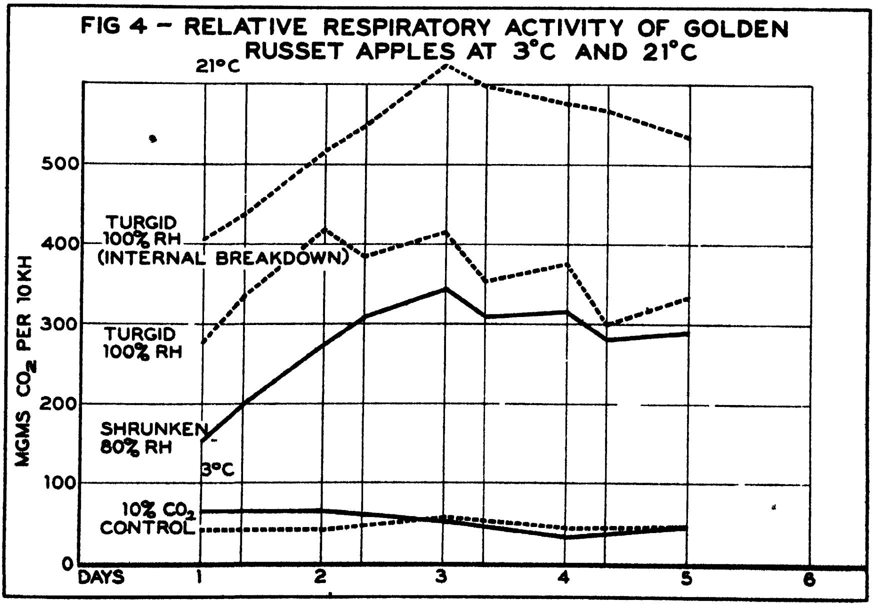

FIGURE 4. Relative respiratory activity of Golden Russet apples at 3° C. and 21° C.

clearly defined. It will be seen, however, that the respiratory ratio of fruits at 3° C. and 21° C. is in the order of 1 : 6 respectively. This ratio closely approximates the 1 : 5.35 ratio obtained by the writer (10) with Bramley's Seedling apples removed from 3° C. to 18° C. Furthermore, fruit stored in air with a relative humidity of 100% results in a higher rate of respiration over that shown by the controls in air at 80 to 85% R. H. when removed from 3° C. to 21° C. The great increase in carbon dioxide output of fruits affected by internal breakdown is also worthy of note.

In order to evaluate the size effect, not only in regard to carbon dioxide output but also to moisture loss, the three treatments, namely, shrunken controls, turgid controls, and those apples stored in 10% carbon dioxide, were duplicated using large and small fruits (three apples per sample). For determination of moisture loss the fruit was weighed both at the commencement and at the end of the experiment.

TABLE 2.- TOTAL CARBON DIOXIDE AND MOISTURE LOSS OF GOLDEN RUSSET APPLES AT 21° C.

Treatment	Weight of sample (in grams)	CO_2 loss (mgms. per kilo.)	Moisture loss (mgms. per kilo.)	Moisture/ CO_2
Shrunken (85% RH)	266.65	2503	8362	3.3
Shrunken (85% RH)	150.34	2649	9376	3.5
Turgid (100% RH)	256 84	3238	6262	1.9
Turgid (100% RH)	180.87	4600*	16497*	3.5
Turgid (10% CO_2)	210.23	3299	8525	2.6
Turgid (10% CO_2)	158.68	2912	9692	3.3
			Average	3.9

* Apples affected with internal breakdown.

Table 2 indicates that size is an important factor in the determination of relative rates of transpiration in that the ratio of surface area to bulk decreases with size increase, and thus the smaller fruits exhibit higher rates of transpiration than the larger fruits. The size effect is not so marked in relation to respiration in this test, and may be due to diffusion interference as brought about by the senescent condition of the internal tissues of the fruit. It is of interest to note that the ratio of the rates of respiration and transpiration in Golden Russet apples is approximately 1 : 3.

The first test with Golden Russet apples failed to clearly differentiate the carbon dioxide and high humidity effects. The experiment was therefore repeated, omitting the shrunken fruits; the two series were run in triplicate again using large and small apples. It will be seen from Figure 5 that the fruits stored under high humidity conditions respired more rapidly than those removed from 10% carbon dioxide (both previously stored at 3° C.); in addition, the moisture loss of the former sample was found to be 1.7 times greater than in the latter. Size relationships were again apparent in this experiment, but the results shown in Figure 5 are on an equivalent weight basis.

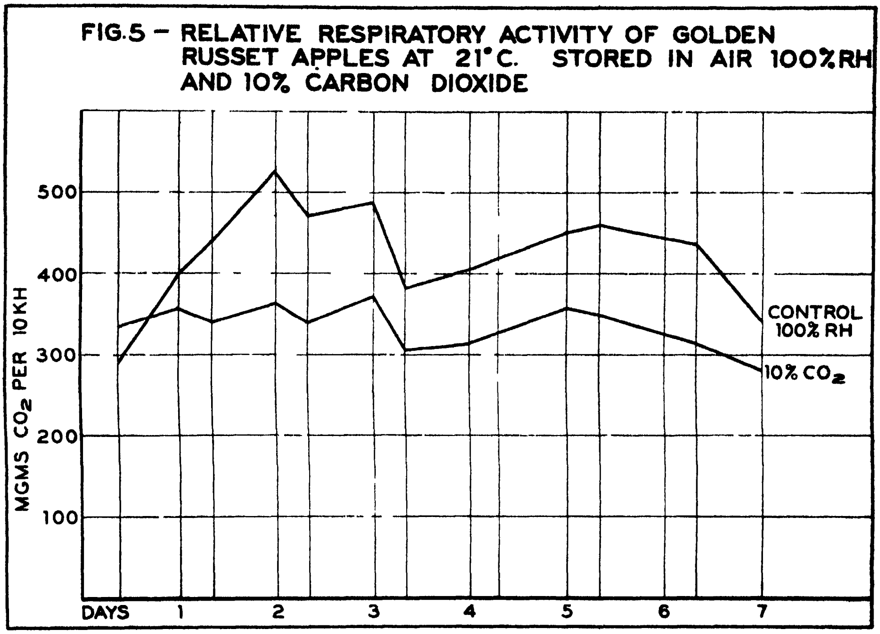

FIGURE 5. Relative respiratory activity of Golden Russet apples at 21° C. Stored in air 100% RH and 10% carbon dioxide.

Apples of the McIntosh variety stored in 5 and 10% carbon dioxide and in air at 3° C. were also transferred to 21° C. for respiration observations and were run in duplicate. Figure 6 shows that the carbon dioxide effect

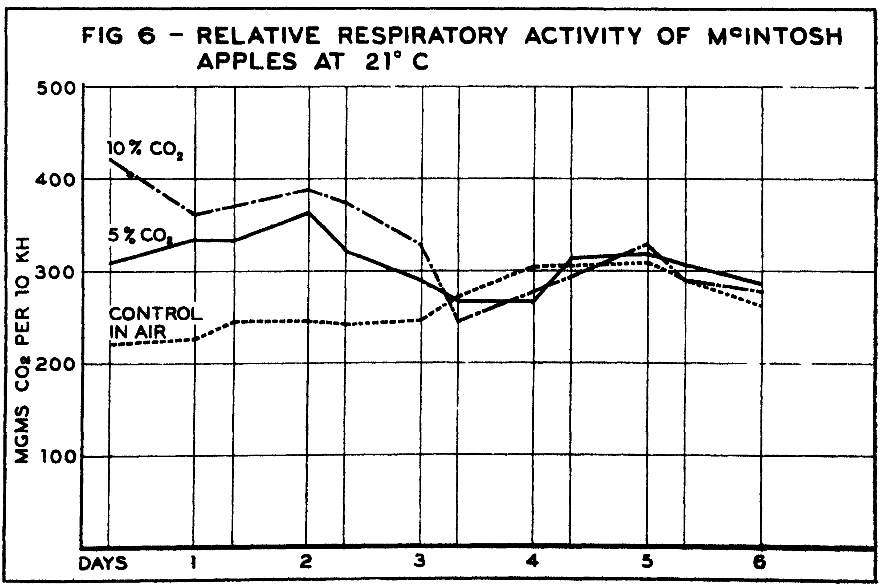

FIGURE 6. Relative respiratory activity of McIntosh apples at 21° C.

is similar to that found with Golden Russet apples except that the McIntosh fruits appear to lose the effect of the gas more rapidly as both the treated and untreated samples respire at the same rate after three days.

Biochemical Changes

Determinations were made on the hydrogen ion concentration and the total acidity (expressed as malic acid); carbohydrates were estimated on frozen macerated tissue. Moisture content was also determined, but the data obtained has been linked up with osmotic relationships of the treated fruits.

The juice was expressed from 10 apples in each treatment by means of an ordinary food grinder and a small hand press. Hydrogen ion concentrations were determined with a quinhydrone electrode apparatus, and the total acidity by titration against a standard solution of 0.1 N sodium hydroxide using phenolpthalein as the indicator.

Sugars were determined by the modified Munson and Walker (26) method which depends on the ratio of copper reduction to sugar oxidation in an alkaline solution. The major modification of the original method is the substitution of a citrate-carbonate reagent in the place of the Fehlings solution (Shaffer and Somogyi (29), Scoggan (30)). The first pH estimations were made on the treated fruit which was held in common storage, the results being shown in Table 3.

TABLE 3.—pH VALUES OF EXPRESSED JUICE OF APPLES HELD IN ARTIFICIAL ATMOSPHERES IN COMMON STORAGE, 3° C. TO 4.5° C.

Variety	Date examined	Control in air	O_2 2.5%	CO_2 2.5%	CO_2 5.0%	CO_2 10%
Russet	30/1/36	3.72	—	—	3.64	3.64
Russet	12/4/36	3.81	—	—	3.81	3.81
McIntosh	30/1/36	3.55	—	3.38	3.38	3.38
McIntosh	12/4/36	3.76	—	3.69	3.64	3.60
Cox Orange	30/1/36	3.64	3.81	3.59	3.64	3.55
Cox Orange	31/4/36	3.94	3.81	3.72	3.98*	3.81

* Apples affected with severe internal breakdown.

The results in Table 3 indicate quite clearly that the hydrogen ion concentration decreases as senesence proceeds, with the fall particularly marked in the McIntosh and Cox Orange apple varieties in which the activity during senescence is much more pronounced than in the Russet variety. With one exception the influence of carbon dioxide appears to be quite consistent, namely, a lower pH value than that obtained in the controls. It has been stated that the method of determination may cause a loss of carbon dioxide, but even if this were the case one might reasonably expect yet lower pH values than those obtained. There are no large differences in the values obtained between the effects of the various concentrations of carbon dioxide; those obtained in the last examination of Cox Orange apples are influenced by the development of incipient breakdown. The

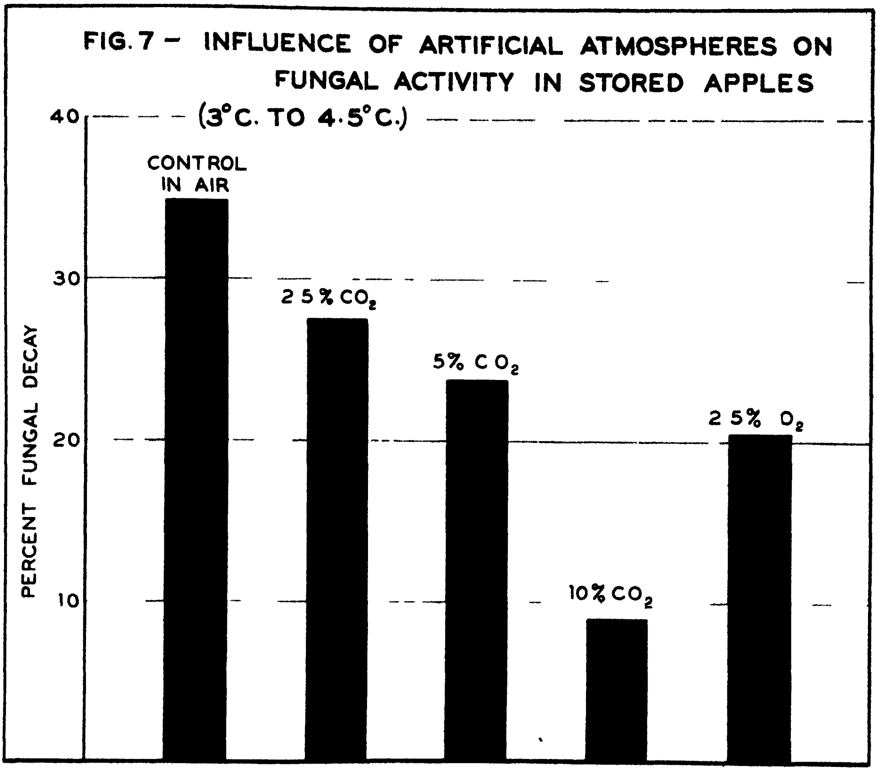

FIGURE 7. Influence of artificial atmospheres on fungal activity in stored apples (3° C. to 4 5° C.).

increase in alkalinity of the juice from the severely-broken-down fruits is particularly noteworthy.

It was decided to follow this investigation further, and at the commencement of the 1936 storage season samples of Gravenstein apples and Clapp Favorite pears were picked and immediately stored in containers with atmospheres of 100% carbon dioxide and 100% nitrogen for one week. The samples under the latter conditions were flushed with pure nitrogen every 24 hours until no carbon dioxide could be detected. Four temperatures were used: 0° C., 4.5° C., 10° C. and 18° C.

TABLE 4.—THE INFLUENCE OF ARTIFICIAL ATMOSPHERES UPON THE pH VALUES OF EXPRESSED JUICE OF APPLES AND PEARS AT DIFFERENT TEMPERATURES FOR ONE WEEK

Material	Treatment	Temperature			
		0° C.	4 5° C.	10° C.	18° C.
Apple	100% CO_2	3 14	3 17	3 24	3 28
Apple	100% N_2	3 10	3 05	3 17	3,09
Apple	Control in air	3 00	3 09	3.00	3 02
Pear	100% CO_2	4 17	4.41	4.37	4.55
Pear	100% N_2	3 90	4 10	3.90	4.09
Pear	Control in air	3 90	4 00	4.00	4.06

Table 4 shows that the carbon dioxide effects are reversed in relation to the results obtained in the previous experiment in that there is an increase in the alkalinity of the expressed juice which becomes more pronounced at higher temperatures. The greater change shown by the pears than the apples bears out the point that the former are able to absorb carbon dioxide to a greater extent than the latter fruits (13).

On the other hand, fruits in the absence of both oxygen and carbon dioxide show inconsistent effects, but the tendency appears to be in favour of a less acid reaction.

Estimations of total acidity were made in the course of the 1936–37 storage season on a series of treated fruits from common and 3° C. storage, save that the low oxygen and 2.5% carbon dioxide treatments were omitted, and a sample of Golden Russet apples stored in 100% relative humidity was added. The results are shown in Table 5.

TABLE 5.— PER CENT MALIC ACID IN APPLES STORED IN ARTIFICIAL ATMOSPHERE IN COMMON STORAGE (C.S.), 3° C. TO 4.5° C. FOR FIVE MONTHS

Variety	Temperature	Control in air 85% RH	Air 100% RH	CO_2 5%	CO_2 10%
Russet	C.S.	0 235	0.257	0.281	0.300
Russet	3° C.	0.372	0.359	0.370	0.360
McIntosh	C.S.	0.216	—	0.267	0.293
McIntosh	3° C.	0 317	--	0.317	0.359
Cox Orange	C.S.	0.270	—	0.289	0.320
Cox Orange	3° C.	0 349	—	0.331*	0.312†

Apples slightly* and severely† affected with internal breakdown.

Under the higher temperature conditions it will be noted in Table 5 that the carbon dioxide has retarded the rate of acid consumptiom, but that at 3° C. the differences are inconsistent although the acid content is higher than that found under common storage conditions. There is also a decrease in total acidity as well as actual acidity in fruits affected with breakdown.

With regard to the effect of humidity it should be pointed out that the fruits stored at the higher temperatures in relative humidities of 85 and 100% were very shrunken and firm respectively, whilst at the lower temperatures the degree of firmness differed very slightly in the corresponding samples. This variation in moisture loss may account for the conflicting values obtained, but this point requires further investigation.

TABLE 6.—PERCENTAGES OF TOTAL, REDUCING AND NON-REDUCING SUGARS IN COX ORANGE APPLES STORED FOR 3 MONTHS IN ARTIFICIAL ATMOSPHERES AT 3° C. TO 4.5° C.

Treatment	Total	Reducing	Sucrose
2.5% O_2	10.40	7.73	3.22
2.5% CO_2	11.73	7.56	4.79
10.0% CO_2	10.50	7.32	3.73
Control in air	12.53	7.43	5.58

Carbohydrate estimations were confined to the Cox Orange apples. It must be pointed out that the figures shown in Table 6 are purely indicative as the data are insufficient to

warrant definite conclusions being drawn. It may be seen, however, that the low oxygen concentration has apparently accelerated the loss of sucrose as found by Fidler (11), and a similar effect but less marked may be seen in the sucrose value for the 10% carbon dioxide treatment. The control in air is characterized by the least loss in total sugars of all treatments.

Observations were made on the colour changes occurring in the stored fruits and it was seen that all the carbon dioxide treatments and also the low oxygen retarded the yellowing of the ground colour on McIntosh and Cox Orange apples.

Osmotic and Permeability Relationships

The plasmolyticum used in the determination of osmotic values and of permeability was calcium chloride, as it has been shown that this solution is unable to enter plant cells. Furthermore, the solution will last several months according to Levitt and Scarth (23). The chief objection to the use of sucrose is that of nicro-organic development and this was observed in the course of these investigations. Osmotic values were estimated to within 0.01 M and a series of solution were made up from 0.1M to 1M calcium chloride.

The osmotic pressures in atmospheres were calculated from the freezing points given in the International Critical Tables according to the equation

$$OP = 12.06 - \Delta 0.021^2$$

in which OP = osmotic pressure and Δ = corrected depression of the freezing point. This equation was also used in connection with the cryoscopic determinations of osmotic pressures.

Neutral red 5 p.p.m. was adopted as the staining medium throughout these cellular studies; the cell walls remain unstained and the dead cells are easily distinguishable by the purplish granulated appearance of the protoplasm. A minimum of ten sections were used for the determination of incipient plasmolysis, this point being reached when over 50% of the cells showed this characteristic.

Cryoscopic determinations were made by means of a Hortvet cryoscope upon juice expressed from freshly thawed macerated apple tissue. Corrections were made for the true depression of freezing point using the tables of Harris and Gortner (15).

Estimations of moisture content were made on 20-gram samples of freshly thawed tissue utilizing two methods: (1) 100° C. for 24 hours, and (2) 50° C. in vacuo for 48 and 72 hours. The figures obtained for the 48-hour period in the second method have been omitted, as it was found that the moisture estimate after 72 hours drying did not exceed by more than 0.1% that obtained after 48 hours.

In Table 7 it will be seen that the pressure in pounds required to break the apple tissue with a penetrometer is included, and also the percentage of total solids as calculated from the refractive index of the juice. An Abbé prism refractometer was used to obtain the refractive index of the juice, and the corresponding percentage of total solids was derived from the International Critical Tables.

TABLE 7.—OSMOTIC PRESSURE MOISTURE CONTENT, TISSUE RESISTANCE AND THE PERCENT TOTAL SOLIDS (EXPRESSED JUICE) OF APPLES STORED IN DIFFERENT ATMOSPHERES IN COMMON STORAGE FOR THREE MONTHS AT 3° C. TO 4 5° C.

Variety	Treatment	*Percentage moisture fresh weight*		*Osmotic pressure in atmospheres*		Pressure in lbs (penetrometer)	Per cent solids
		50° C in vacuo 72 hr	100° C 24 hr	Cryoscopic method	Plasmolytic method		
Golden Russet	Controls	80 85	80 75	24 28	28 02	20 6	16 0
	5% CO_2	81 88	84 31	23 50	25 23	25 0	16 0
	10% CO_2	82 14	85 14	22 36	23 89	23 7	15 6
Cox Orange	Controls	82 49	84 35	22 42	—	15 5	15 2
	2 5% O_2	82 96	85 48	22 72	—	20 5	14 4
	2 5% CO_2	83 10	85 85	19 37	—	16 5	13 8
	5 0% CO_2	82 98	84 76	21 53	—	16 8	13 2
	10 0% CO_2	82 80	85 26	21 88	—	17 3	13 4
McIntosh	Controls	86 67	88 02	15 34	17 40	14 4	11 6
	2 5% CO_2	86 44	88 83	15 94	—	13 1	10 7
	5 0% CO_2	86 46	88 25	16 57	16 77	12 1	11 0
	10 0% CO_2	86 66	89 02	15 73	16 77	12 2	10 7

With the exception of the Golden Russet controls it will be seen that drying at 100° C. for 24 hours gives a consistently higher figure for moisture content than that at 50° C. for 72 hours (Table 7).

There is a general correlation between moisture content, osmotic values, and percentage of total solids from the varietal standpoint. It must be pointed out that the relative humidity was higher in the treated samples than it was in the control lots, and thus the latter are consistently lower in water content and higher in the observed osmotic values. It was found later that Golden Russet apples which had been stored in air, one lot in 100% relative humidity, and another in 85%, showed osmotic pressures of 21.88 and 23 22 atmospheres respectively.

The difference between the osmotic pressures as obtained by the two methods is in keeping with the findings of other workers (2, 9).

The pressure in pounds required to puncture the sub-epidermal tissues of the fruit has been included in order to show in particular the remarkably firm condition of the Cox Orange fruits stored in 2 5% oxygen in relation to the high values obtained for the osmotic pressure, water content and total solids. It would appear, therefore, that low oxygen conditions have been instrumental in retarding the loss of cell wall materials, possibly pectic constituents.

The effect of carbon dioxide would seem to tend toward decreasing the osmotic pressure. The very low value obtained in the Cox Orange apples treated with 2 5% carbon dioxide is attributed to the onset of internal breakdown. A further attempt was made to elucidate the treatment effects by calculating the osmotic values on the basis of the control values for moisture.

The corrected values shown above again indicate that increased carbon dioxide results in a lower osmotic value relative to the controls in air but this point requires further investigation.

Determinations were first made on the permeability of apple cells to various solutes, neutral red being used as the staining medium. The

TABLE 8.—OSMOTIC PRESSURES OF APPLE CELLS (CORRECTED FOR MOISTURE) STORED IN DIFFERENT ATMOSPHERES FOR THREE MONTHS AT 3° C. TO 4 5° C.

Variety	Control in air	2 5% O_2	2 5% CO_2	5% CO_2	10% CO_2
Golden Russet	24 38	--	—	23 10	21 20
Cox Orange	22 42	22 6	19 20	21 75	21 75
McIntosh	15 34	—	16 05	16 65	15 75

following non-electrolytes were included: glycol, thiourea, urea, glycerol, and sucrose; also one electrolyte, namely, potassium nitrate. Sections were placed in twice isotonic solutions of the above substances and examined at 5-minute intervals for signs of deplasmolysis. It was found that the solutions of glycol and urea caused no plasmolysis, and there was only slight plasmolysis of the cells for 5 minutes with thiourea and glycerol. On the other hand, both sucrose and potassium nitrate produced strong plasmolysis in 5 minutes; the latter solute, however, was more powerful in its action, but neither of them showed signs of deplasmolysis at the end of 45 minutes after which time all the cells were dead. With the exception of thiourea it may therefore be concluded that the more polar the compound is the more impenetrable does the cell become to the same.

During the course of the above tests vacuolization was noted in carbon-dioxide-treated cells placed in thiourea and sucrose as shown in Figure 8. It is of interest to note that difficulty was experienced in obtaining these photographs as the vacuoles disappeared after a time. A peculiar characteristic which was observed in cells plasmolysed in a normal sucrose solution is shown in Figure 9. It would almost seem that there are two distinct membranes on the edge of the large vacuole in the centre cell; moreover, when the cell was observed prior to being photographed, the second or outer membrane was more pronounced and at a greater distance from the vacuole. There is the possibility, however, that in the process of plasmolysis a portion of the interior of the cell wall was drawn away with the protoplasm.

The relative permeability of cells to water in the case of treated Golden Russet apples was determined by measuring the time required for the cells to deplasmolyse. This was done by plasmolysing the cells in a twice isotonic solution of calcium chloride. They were left in this solution for about 20 minutes and then transferred to a half isotonic solution of the same salt for deplasmolysis. The average rate of permeability for 20 cells is shown in Table 9.

TABLE 9.—THE INFLUENCE OF CARBON DIOXIDE IN THE PERMEABILITY OF APPLE CELLS (3 MONTHS IN COMMON STORAGE, 3° C to 4 5° C) AVERAGE OF 20 CELLS

Treatment	Time required to reach incipient plasmolysis (min)
Control in air	8
5% CO_2	6
10% CO_2	5

The figures given clearly indicate the increase in permeability of apple cells as a result of carbon dioxide treatment. This study was confined to the Golden Russet variety owing to sectioning difficulties with the other fruits. Nevertheless, in order to further substantiate these findings,

other studies were undertaken at the commencement of the next season with freshly-picked fruits. Samples of Gravenstein apples and Clapp Favourite pears were placed in containers, the atmospheres in which were as follows: 100% carbon dioxide, 100% nitrogen, and a control in air. Four temperatures were used: 0° C., 4.5° C., 10° C. and 18° C. A similar procedure to that described in the previous experiment was used.

TABLE 10.—THE INFLUENCE OF CARBON DIOXIDE AND NITROGEN ON THE PERMEABILITY OF THE CELLS OF APPLE AND PEAR FRUITS STORED FOR ONE WEEK AT °0 C., 4 5° C., 10° C. and 18° C.

Fruit	Temperature, degrees Centigrade	Time required to reach incipient plasmolysis (min.)		
		Control in air	100% CO_2	100% N_2
Pear	0	13 4	6 8	14 9
	4 5	7 7	9 0	12 0
	10	16 6	10 9	12 0
	18	12 5	12 0	7 0
Apple	10	15 0	7 0	20 0
Average for pears (all temperatures)		16 7	12 9	14 8

The results shown in Table 10 again indicate that carbon dioxide increases the permeability of cells to water; the results, however, with tissues stored in the absence of oxygen are not consistent. Temperature effects are not well defined although there is a consistent decrease in the permeability of the carbon dioxide series as the temperature is raised.

The viscosity of the apple and pear cells was tested by placing blocks of tissue in isotonic solutions and centrifuging them; sections were then taken from the tissue and examined as to the position of the starch grains. It was found that starch grains in the Gravenstein apple were thrown down too quickly (2 minutes) for timing purposes. The grains in the Clapp Favourite pears moved more slowly; accordingly, four samples of treated pears were tested as above; namely, in air, 100% carbon dioxide, and 100% nitrogen, each at 4 5° C., and 100% carbon dioxide at 18° C. This series was centrifuged for 5-minute intervals, in which it was observed that no movement of starch grains had taken place in the control and in the 100% nitrogen-treated apples, whereas in the carbon dioxide series there was a heavy accumulation of grains at the ends of the cells of tissues treated at 4.5° C., but only a slight movement had taken place in those tissues treated at 18° C. The temperature influence may be accounted for by the increased solubility of carbon dioxide at lower temperatures.

The permeability of apple tissues as measured by the diffusion of electrolytes into solutions of distilled water was studied in order to verify the foregoing data if possible. This was accomplished by placing discs of apple tissue in distilled water of a known electrical conductivity and measuring the decrease in resistance at 24-hour intervals.

Preliminary readings were made on uniform cylinders of tissue from apples which had been treated; the tissues from the 2.5 and 5% carbon dioxide treatments were affected with physiological breakdown and the increased leaching of ions from these cells is clearly evident (Table 11).

TABLE 11.—ELECTRICAL CONDUCTIVITY OF LEACHINGS FROM COX ORANGE APPLE TISSUES STORED IN ARTIFICIAL ATMOSPHERES (EXPRESSED AS RECIPROCAL OHMS $\times 10^5$ AFTER 24 HOURS)

Variety	Control in air	Treatment			
		2 5% O_2	2 5% CO_2	5% CO_2	10% CO_2
Cox Orange	600	540	680*	666*	600

* Apples affected with internal breakdown.

The figures do not indicate a carbon dioxide effect when the controls and 10% carbon dioxide are compared, but the low permeability of the tissues stored in 2 5% oxygen is striking, also that obtaining in diseased tissue.

In view of the above results another experiment with Golden Russet apple tissue was set up in triplicate. Cylinders of tissue were removed from the apples by means of a cork borer (0.65 cm. bore) and cut up into discs 0.25 cm. thick. Discs of each sample were then placed in 50 cc. of distilled water, the conductivity of which was determined and found to be uniform. Three readings were made at 24-hour intervals, the fourth being discarded on account of mould development.

TABLE 12.—ELECTRICAL CONDUCTIVITY OF LEACHINGS FROM GOLDEN RUSSET APPLE TISSUE STORED IN ARTIFICIAL ATMOSPHERES FOR FOUR MONTHS (EXPRESSED AS RECIPROCAL OHMS $\times 10^5$)

Variety	Time in hours	Serial number	Treatment		
			Control in air	5% CO_2	10% CO_2
Golden Russet	24	1	125	113	126
	24	2	126	113	126
	24	3	Lost	113	126
	48	1	145	156	178
	48	2	145	154	180
	48	3	—	153	180
	96	1	166	178	200
	96	2	166	180	200
	96	3	—	180	200

The permeability as shown in Table 12 is apparently increased by the carbon dioxide effect when the later conductivity measurements are compared. The first reading after 24 hours may be affected by the initial wounding of the tissues because thereafter the conductivity of leachings from sample to sample is quite consistent.

Fungal Activity

Two examinations of the stored fruits were made in order to determine the wastage due to fungal decay. The total decay for all varieties under each treatment is shown in Figure 7, the inhibitory effect of the artificial atmospheres employed being clearly demonstrated, particularly in 10% carbon dioxide. Examination of the data reveals, however, that the retarding influence of carbon dioxide and low oxygen is more marked in the early stages of storage as shown in Table 13.

TABLE 13.—PERCENTAGE OF FUNGAL DEVELOPMENT ON APPLES STORED IN DIFFERENT ATMOSPHERES FOR THREE MONTHS AT 3° C TO 4 5° C

Variety	Treatment	Examined		10
		25/1/35	1/4/36	
Cox Orange (1)	Control in air	18 0	31 5	1 72
Cox Orange (2)	Control in air	16 0	60 0	3 74
McIntosh	Control in air	42 0	63 6	1 54
Cox Orange (1)	10% CO_2	2 0	26 3	13 50
Cox Orange (2)	10% CO_2	2 0	17 4	8 20
McIntosh	10% CO_2	0 0	20 0	20 00
Cox Orange (1)	2 5% O_2	10 0	24 0	2 40
Cox Orange (2)	2 5% O_2	4 0	41 0	11 00

In order to determine the influence of these same atmospheres upon the pure cultures of *Penicillium expansum* (the organism almost entirely responsible for the wastage observed in these experiments), isolations were made from decayed fruits and transferred to slants of sterile media (potato dextrose agar). After about two weeks the slants were examined and transfers were made from the pure cultures to petri plates (three for each treatment); these were immediately placed in the storage containers and the lids of the dishes removed. The control containers were covered with cheese cloth in order to eliminate contamination from the outside air as far as possible without interfering with the atmospheric conditions

First of all, however, preliminary tests were made with sterile plates which were placed in the various atmospheres for 6 days in order to ascertain the degree of contamination to be found under such conditions. It is clear from an examination of Figure 10 that the infectivity of spores is considerably reduced by carbon dioxide and to a lesser extent by low oxygen. The influence of these same atmospheres on pure cultures of *Penicillium expansum* for a period of 12 days is shown in Figure 11. The following observations were made.

The control in air was characterized by heavier sporulation than was seen in all the other treatments, but growth was much the same as in 2 5 and 5.0% carbon dioxide; it is possible, therefore, that in the case of the controls, growth was retarded by the sporulating activities of the colony.

The colonies in 10% carbon dioxide and 2 5% oxygen showed less growth than in all other treatments and also less sporulation. In addition, the colony in 2 5% oxygen was peculiar in that aerial white mycelium developed in contrast to the depressed appearance of the other colonies.

Observations were also made after the plates were removed to room

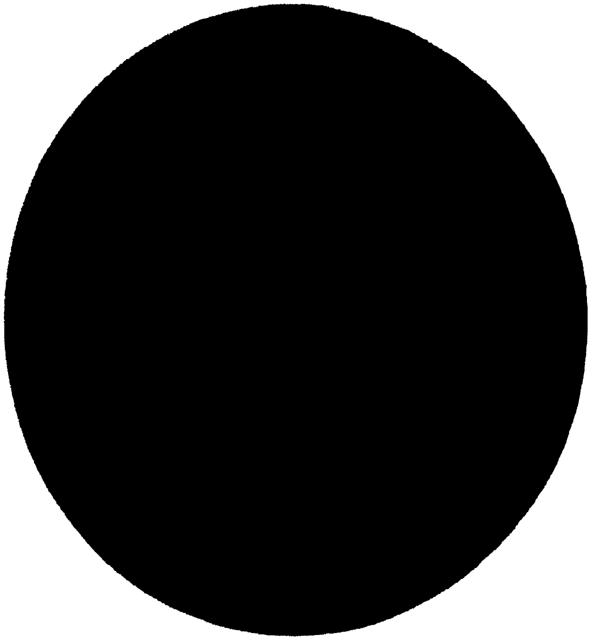

FIGURE 8. Plasmolyzed apple cells showing vacuolization (stained with neutral red).

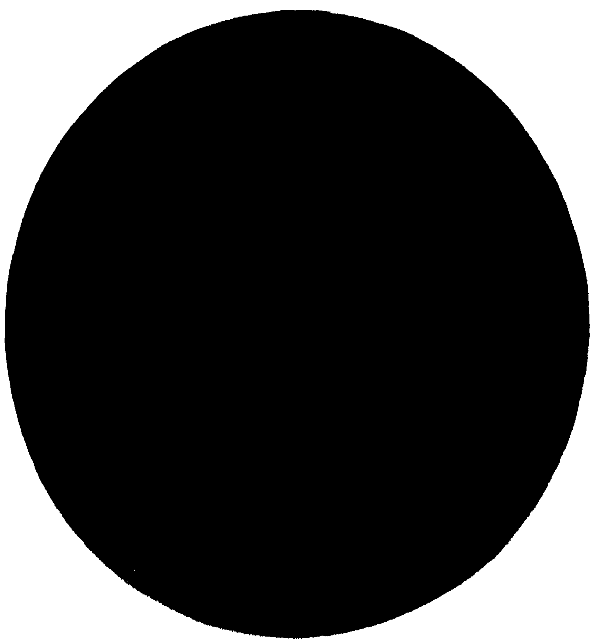

FIGURE 9. Plasmolyzed apple cells showing "double membrane" effect (stained with neutral red).

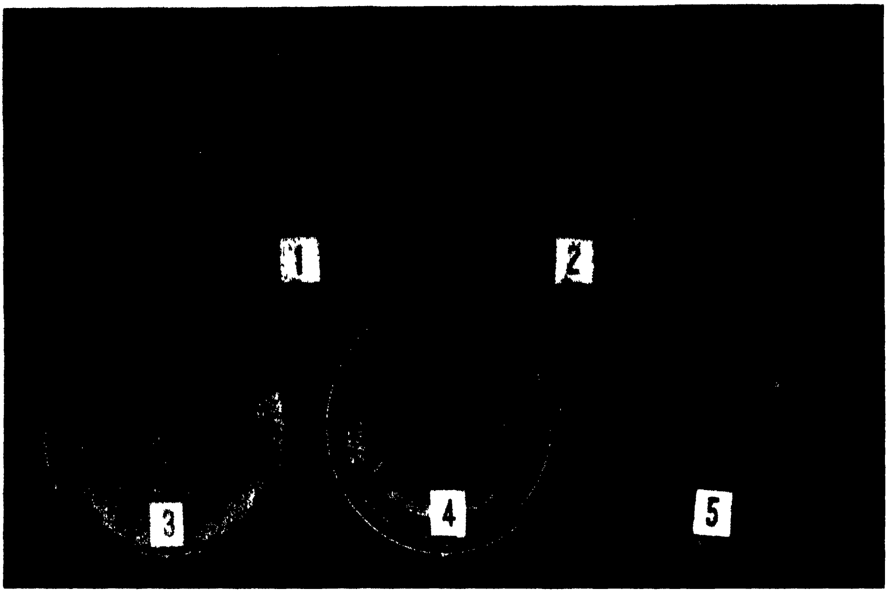

FIGURE 10. The influence of artificial atmospheres upon the growth of fungal spores on sterile media (Petri plates placed in apple storage containers). 1. Stored in air; 2. 2.5% O_2; 3. 2.5% CO_2; 4. 5.0% CO_2; 5. 10.0% CO_2.

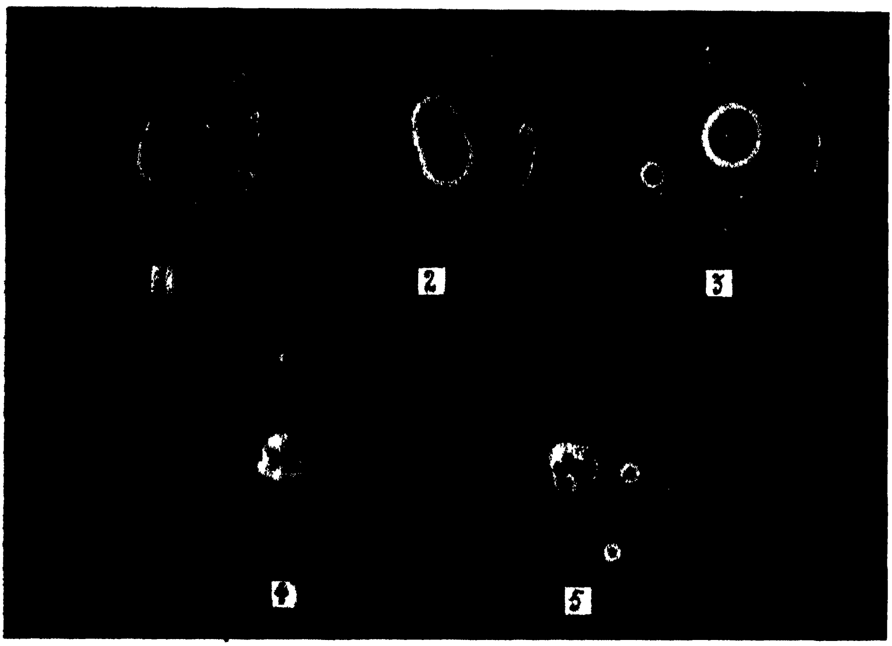

FIGURE 11. The influence of artificial atmospheres upon the growth of colonies of *Penicillium expansum*. 1. Stored in air; 2. 2.5% CO_2; 3. 5.0% CO_2; 4. 10.0% CO_2; 5. 2.5% O_2.

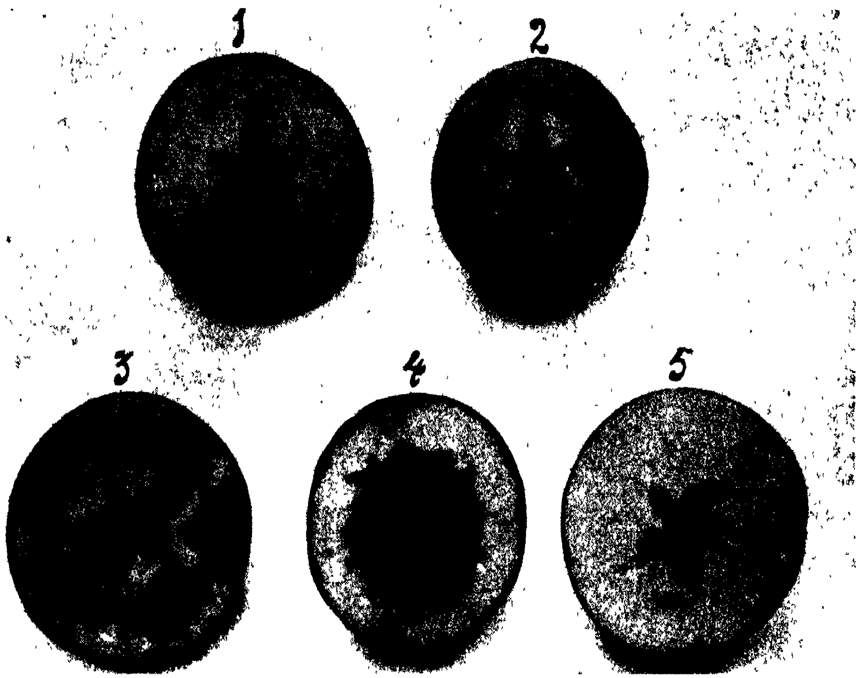

FIGURE 12. Physiological breakdown of Cox Orange apples stored in artificial atmospheres at 3° C. to 4.5° C. 1. Stored in air; 2. 2.5% CO_2; 3. 5.0% CO_2; 4. 10.0% CO_2; 5. 2.5% O_2.

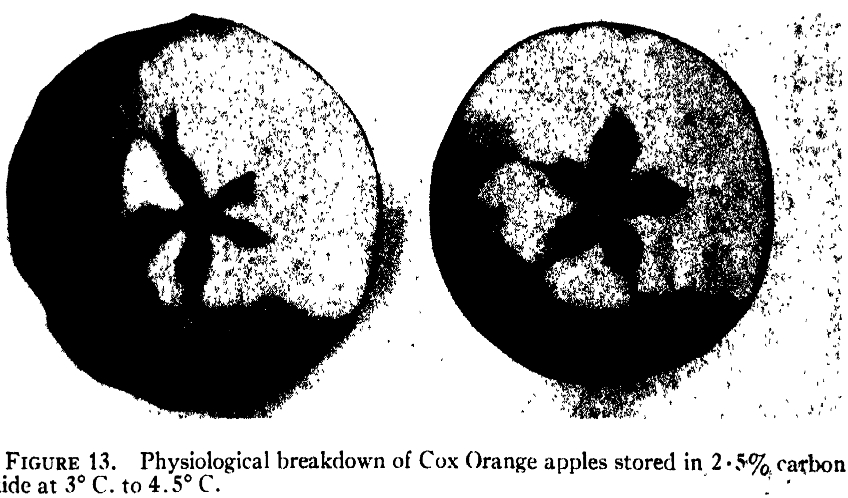

FIGURE 13. Physiological breakdown of Cox Orange apples stored in 2·5% carbon dioxide at 3° C. to 4.5° C.

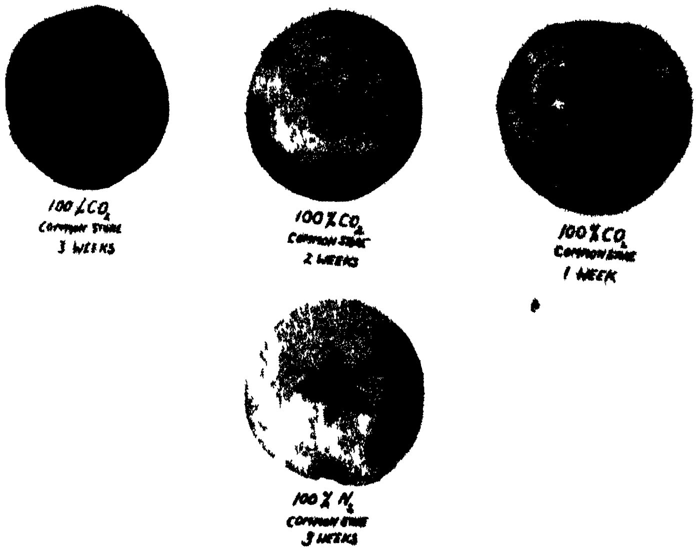

FIGURE 14 Physiological breakdown of McIntosh apples stored in 100% carbon dioxide and 100% nitrogen

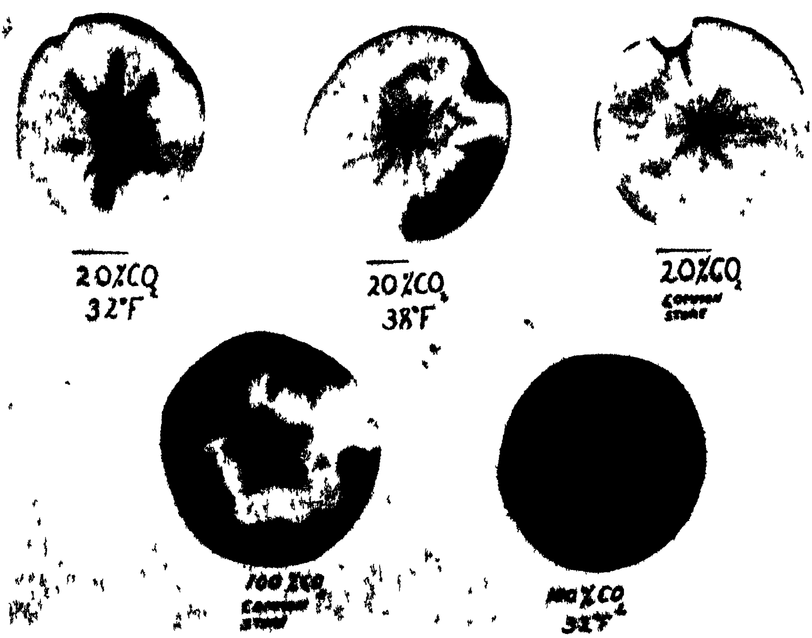

FIGURE 15. The influence of temperature on the breakdown of McIntosh apples stored in 20% carbon dioxide

temperatures in air and it was seen that the control rapidly increased growth and sporulating activities as did the colony stored in 2.5% oxygen. On the other hand, the carbon dioxide treated cultures showed a slow reaction to environment, particularly that in 10% carbon dioxide, which might possibly indicate that the media had become toxic as a result of the atmospheric conditions during treatment.

Physiological Disorders

McIntosh apples stored in 10% carbon dioxide possessed a very pronounced alcoholic flavour, the samples in 5% concentration were slightly off flavour but those in 2.5% concentration remained in excellent condition. The low average temperature (3° C.) during the latter part of the storage season may account for the flavour developed in the sample stored in 5% carbon dioxide. No wastage due to functional disorders was observed with this variety with the exception of a slight corticle flush which appeared in the controls in air. Golden Russet apples remained in perfection condition in both 5 and 10% carbon dioxide concentrations until the sixth month when it was observed that a mottled type of scald had made its appearance. In the 5% carbon dioxide treatment, 77% of the apples were scalded, whereas in the 10% series only 31% were affected. The necessity of wrapping fruits of this variety in oiled paper for storage under such conditions at once becomes apparent. The controls in air were only characterized by heavy shrinkage. Duplicate samples of all treatments in the Cox Orange series were carried in storage. Table 14 shows the results obtained.

TABLE 14.—FUNCTIONAL DISORDERS AND FLAVOUR OF COX ORANGE APPLES STORED IN ARTIFICIAL ATMOSPHERES IN COMMON STORAGE (3° C. TO 4.5° C.)

Serial number	Per cent CO_2	Per cent O_2	Per cent breakdown Examined 25/1/36	Per cent breakdown Examined 13/4/36	Flavour 25/1/36
14	0 0*	2 5	—	—	Slightly bitter
15	0 0*	2 5	—	–	Slightly bitter
12	2.5	18 5	20.0	21.0	Good
13	2 5	18 5	10.0	50.0	Good
8	5.0	16.0	22.0 (heavy)	72 7	Good
9	5.0	16 0	2.0	100 0	Good
10	10.0	11.0	—	47 4	Slightly alcoholic
11	10 0	11.0	—	35 5	Slightly alcoholic
Control	—	—	—	- -	Mealy (No flavour)

* Determined.

Table 14 indicates that the onset of functional disorders is induced by increased carbon dioxide concentrations, and that apart from deleterious effects upon the flavour the low oxygen treatment and the controls constituted the best treatments (see Figure 12). The low oxygen concentration, furthermore, is characterised by very hard firm fruits which corresponds with observations made by the writer on pears treated in a

similar manner. The relatively high percentage of breakdown in the 5% carbon dioxide series is particularly striking. The appearance of the breakdown as found in each treatment is shown in Figure 12 and it would seem that the physiological effects are more or less specific. In Figure 13 it will be seen that the disorder in apples stored in 2.5% carbon dioxide is confined to the peripheral tissues, a characteristic of mealy breakdown. Furthermore, Table 14 shows that breakdown in the first examination was confined to the 2.5% and 5% series. The latter samples were not so markedly affected in the peripheral areas but rather more so in the vascular areas. The apples stored in 10% carbon dioxide are in contrast to the above treatments in that disintegration of the tissues is more or less limited to the core area including the 10 main vascular bundles.

Careful comparison with the illustrations of mealy breakdown and brown heart as shown in the publication by Plagge and his associates (28) would indicate that the 2.5 and 5% treatments are types of mealy breakdown, while 10% carbon dioxide has induced brown heart.

Observations on the effects of atmospheres devoid of oxygen upon McIntosh and Stark apples at room temperature after storage at 3° C. for 4 months showed that both varieties developed breakdown which resembled soggy breakdown. This type has been previously noted at the Kentville Experimental Station in McIntosh apples exposed to 100% nitrogen at 0° C. for 3 weeks after 2 months storage, but did not appear until a month later in common storage (see Figure 14). The disorder usually arises in the corticle region of the apple as scattered light brown patches. At first these are well defined, but they gradually merge into a band-like area of soft tissue, approximately 0 5 cm. from the epidermis, as seen when an affected apple is halved at right angles to the core line. This band of dead tissue may or may not completely surround the cortex, but in the advanced stages of development the healthy sub-epidermal tissue gradually breaks down, which is followed by external browning of the apple skin and final disintegration of the entire fruit. As will be noted from the above table, low oxygen conditions produced a bitter flavour in the fruit and which was more marked in apples stored in pure nitrogen immediately after harvesting for a period of one week.

Finally the effects of high concentrations of carbon dioxide upon McIntosh apples are shown in Figures 14, 15; it was noted that very pronounced alcoholic flavours developed in the fruits and that the degree of tolerance toward the gas was less at low temperatures.

DISCUSSION

These investigations have been directed toward a consideration of the physiological effects of artificial atmospheres upon the cellular activities of senescent fruits. It has been shown that the total carbon dioxide output of apples is depressed and stimulated by high (53.5%) and low (6.2%) concentrations of carbon dioxide, respectively, during a period of 5 days. It is necessary, however, to bear in mind the findings of Kidd, West and Kidd (21) who have shown that prolonged storage in 5 and 10% carbon dioxide depresses the respiratory activity of fruits. The development of alcoholic flavours under conditions of high carbon dioxide would point to a stimulation of the anaerobic fermentation system in the cell.

The increase in carbon dioxide output of fruits which were removed from air to pure nitrogen may be due in part to the expulsion of carbon dioxide within the tissues as suggested by Gustafson (14) and to the protective role of aerobiosis in relation to anaerobiosis as postulated by Blackman (3). The corresponding increase in carbon dioxide evolution from apples when removed from high concentrations of the same gas to air also indicates a rapid expulsion of carbon dioxide and possibly the temporary nature of the narcotic influence exerted by carbon dioxide (12, 33). Further the oxygen uptake of the nitrogen-treated fruits when returned to air was lower than that which obtained in those stored in air in spite of the greater carbon dioxide output of the former. It would appear, therefore, that anaerobic processes were still functioning in the treated fruits when stored in air. No evidence was obtained however regarding the extinction point (E) of fermentation in these fruits (31).

The respiratory activity of fruits was determined in air at 3° C. and at 21° C.; the apples used had been stored in 5 and 10% carbon dioxide for approximately 4 months. It was observed that the treated apples evolved a greater amount of carbon dioxide than the controls upon removal to 21° C. The higher value may be due first to the higher concentration of respirable substrate, and second to the disappearance of accumulated carbon dioxide within the tissues. The first explanation is of interest when it is remembered that the Golden Russet apples stored in a relative humidity of 100% in air evolved as much or more carbon dioxide than did the treated fruits. The importance of moisture relationships at once becomes apparent, and in this connection it was found that apples of the same variety lost approximately three times as much moisture as carbon dioxide. In contrast Wardlaw and Leonard (37) report that tropical fruits lose 10 times as much water as carbon dioxide. It was found that the loss of these constituents from apples varied inversely as the size.

A marked deceleration in the rate of loss of total acids in fruits stored in carbon dioxide was observed. Magness and Diehl (24) found that acid loss increased in Delicious and Winesap apples stored in carbon dioxide. Kidd, West and Kidd (21) on the other hand showed that the acid loss was retarded in Bramley's Seedling apples stored in 10% carbon dioxide.

Juice from apples stored in low concentrations of carbon dioxide for 3 months was characterized by a lower pH value than that obtained with juice from air-stored fruits; a higher pH value was obtained, however, when apples were subjected to 100% carbon dioxide for one week. Nevertheless, Thornton (35) states that carbon dioxide in the presence of oxygen decreases the hydrogen ion concentration in a wide range of plant tissue including the McIntosh apple, both in high and low concentrations of carbon dioxide at 25° C. On the other hand, potato tubers treated with 100% carbon dioxide increased in acidity. No significant changes were found in the pH values of cherries, plums and peaches which had been treated with 50% carbon dioxide according to Miller and Dowd (25). Jacobs (17) has shown that carbon dioxide has a specific effect as an undissociated gas producing lethal effects at an increased hydrogen ion concentration.

Pure nitrogen and low oxygen treatments had little effect upon the hydrogen ion concentration of apple juice although there was a slight tendency toward a less acid reaction. Fidler (11) has shown that rate of acid

loss in apples and oranges remains unaffected by the absence of oxygen. He suggests that acid loss is not due to oxidation to carbon dioxide but rather that it undergoes reduction with the evolution of oxygen which could in turn oxidize some intermediate product of carbohydrate metabolism.

Loss of carbohydrates as total sugars appeared to be increased by storage in both 10% carbon dioxide and 2.5% oxygen; this was more marked in the sucrose fraction, particularly under the latter conditions. These findings are in accord with those of Kidd, West and Kidd (21) in regard to the carbon dioxide effect, and with those of Fidler (11) who found that sucrose is lost more rapidly under anaerobic conditions.

The data obtained on osmotic values were complicated by the presence of lower relative humidities in the control containers than in those containing artificial atmospheres. Nevertheless the carbon dioxide treatments appeared to reduce, and the low oxygen to increase, the osmotic pressure in apple cells relative to the controls in air. There was found to be a varietal correlation between osmotic pressure, water content and the percentage total solids in the juice. That there is a wide variation in the osmotic values of cells in different varieties of apples is supported by the work of Chandler (7). Walter (36) lists the following fruits together with the respective osmotic pressures in atmospheres: apples, 23.81; grapes, 28.0; tomatoes, 8.79; and citrus fruits, 14.0.

It has been shown that carbon dioxide increases the permeability of the cells both to water and to leachings. Furthermore, apolar compounds such as urea, penetrate into the cell, while calcium chloride and potassium nitrate, which are strongly polar, failed to enter. These findings are in line with the work of Jacobs (19) who observed that the penetrability of solutes is a function of lipoid solubility supports the hypothesis of Overton (27) that the plasma membrane of the cells is composed largely of water with a differential lipoid phase. Heilbrunn (16) points out that carbon dioxide is frequently used as an anaesthetic in physiological studies and thus may cause dissolution of the lipoid phase (a characteristic of anaesthetics). This observation is borne out by the findings of Jacobs (18) who noted that with *Spirogyra* short exposures of carbon dioxide brought about a liquefaction of the protoplasm while long exposures caused coagulation. In studies on the carbon dioxide narcosis of *Nitella*, Fox (12) observed an increase in the permeability of cells, vacuolization and cyclosis or stoppage of protoplasmic streaming which he suggests is due to the gelation of the colloidal matrix as seen by the jerky motions of the granules (unlike Brownian movement) caused by the kinoplasm (or streaming plasm) when the granules become fixed in the gel.

No consistent differences between the fruit held in low oxygen and in air were noted in relation to water permeability.

Several investigations have shown that carbon dioxide produces an inhibitory influence upon the growth of fungal organisms (4, 5, 6). These studies further substantiate these findings; fungal activity was definitely retarded by 10% carbon dioxide concentrations and to a lesser extent by lower concentrations of the same gas and 2.5% oxygen. This inhibitory influence, however, appeared to lessen in the later stages of storage. Pure cultures of *Penicillium expansum* exposed to similar treatments were also

retarded in growth and sporulation was reduced. It was observed that the colonies subjected to 10% carbon dioxide for 9 days and then placed in air did not exhibit the rapid recovery that was shown by the colonies stored under low oxygen conditions. This continued growth retardation of the carbon-dioxide-treated colonies when removed to air may have been due to the acidification of the media or to the alkaline reaction of fungal hyphae as shown by Thornton (34).

The final stages of the senescent activities of fruit are characterized by physiological breakdown of the tissues, but a detached analysis of these activities is rendered extremely complex due to the inherent varietal reactions of fruits to environmental influences both before and after removal from the tree. The chemical studies on the physiology of apples by Archbold (1), also those of her colleagues, are invaluable contributions in this field of investigation.

It has been found in these studies that physiological breakdown of the apple is associated with marked increases in the respiratory activity, transpiration, permeability and the alkalinity of cells so affected. The accelerated loss of sugars, as seen with apples treated with low oxygen concentrations, did not appear to induce disorganization of the cells; indeed these fruits were shown to have relatively high osmotic pressures, percentage of total solids and moisture content. Furthermore, if it be assumed that the strength of the cells can be gauged by the amount of pressure required to break the same with a penetrometer, then these cells which were subjected to low concentrations of carbon dioxide and also oxygen are high in cell wall materials such as pectins and cellulose.

From the evidence obtained, it is apparent that the substrate for respiration must consist not only of the carbohydrates in the cell but also certain cell wall constituents, because in atmospheres in which there is a low rate of oxidation the disappearance of pectic materials is apparently retarded. Furthermore, it is thought that the supply of acid is not necessarily limited by the amount of sucrose present.

The increase in the permeability of carbon-dioxide-treated (2.5 and 5%) cells may possibly be attributed to the dilution of protoplasmic colloids, in view of the relatively high water content of these tissues; this is partially supported by the relatively high respiration rates of turgid fruits. The only explanation that can be offered for this increase in permeability, which is characteristic of physiological disturbances, is that it may be offset by the slow rate of oxidation under such conditions.

The breakdown occurring under the above conditions has been designated as "mealy breakdown" and is possibly due to the combined effect of low temperatures and carbon dioxide.

Excessive concentrations of carbon dioxide have been shown to induce the condition known as "brown heart" which is usually initiated in the core area of senescent fruits where the internal concentration of carbon dioxide is relatively high. This disease has been described in detail by Kidd and West (22).

Fruits which had been stored for a prolonged period at 3° C. were found to break down after exposure to 100% nitrogen at 21° C.; there was also a loss of red pigmentation in these apples. No such disturbances were noted, however, in the freshly picked apples under similar conditions.

It is possible, therefore, that these physiological responses in the senescent fruits were due to the run-down state of the enzymatic system and its consequent inability to withstand withdrawal of the oxygen supply.

The superficial scald on Golden Russet apples which appears very late in the storage season in carbon dioxide is difficult to explain. It may be that the extinction point (E) for these fruits is reached at the time of scald development and that some product of anaerobic fermentation, as, for example, acetaldehyde, proved toxic to the epidermal cells. Davis and Blair (8) recommend the use of oiled wraps for the prevention of scald in apples stored in artificial atmospheres.

In conclusion, we have seen that storage in carbon dioxide produces certain cellular changes typical of undesirable physiological conditions within the cell. It is believed, however, that the slow rate of oxidation of cell wall materials in low concentrations of carbon dioxide is of considerable importance in the longevity of the cell. Furthermore, the retardation of acid loss by carbon dioxide below a certain critical concentration is possibly responsible for a high degree of peptization being maintained in the protoplasmic colloids, a condition which prevents dehydration and final coagulation of the protoplasm.

SUMMARY

The influence of carbon dioxide and low oxygen concentration on the physiological activities of apple tissue has been studied.

It has been shown that low (6.2%) and high (53.5%) concentrations of carbon dioxide stimulate and depress respectively the total carbon dioxide output of fruits during a period of 5 days. Low concentrations of oxygen (1%) increased the output of carbon dioxide of apples; when these fruits were returned to air the rate of oxygen uptake was found to be lower than in those fruits stored continuously in air.

Fruits which had been stored in 5% and 10% carbon dioxide at 3.5° C. for several months and removed to 21° C. were observed to respire more rapidly than the controls stored in air.

Moisture loss and the size effect were noted. Golden Russet apples lost 3 times as much moisture as carbon dioxide by weight, and the loss of these constituents from fruits varied inversely as the size. In the fruits which were treated with carbon dioxide (2.5, 5 and 10%), over long periods there was found to be an increased hydrogen ion concentration in relation to the controls in air. A decrease in hydrogen ion concentration of apple and pear juice was observed in fruits stored in 100% carbon dioxide for one week and this was more marked at high temperatures; a slight increase was also seen with fruits kept in 100% nitrogen.

Carbohydrate loss appeared to be accelerated by carbon dioxide treatment, and an increased loss of sucrose in the low oxygen series was evident, but a definite retardation was noted in the loss of total solids in the expressed juice of fruit under the latter conditions as compared with the former.

Apple cells were found to be more permeable to apolar compounds than to polar, and carbon dioxide increased the permeability of cells to water, particularly at low temperatures, as measured plasmolytically. The electrical conductivity of leachings (electrolytes) from tissues immersed

in distilled water indicated that carbon dioxide increased the permeability of cells, but that low oxygen caused a decrease.

Fungal invasion was retarded by carbon dioxide and to a lesser extent by low oxygen. Colonies of *Penicillium expansum* were likewise retarded both in growth and sporulation.

Two types of physiological breakdown in Cox Orange apples were observed; namely, "brown heart," due to excessive carbon dioxide concentration (10%), and a condition similar to "mealy breakdown" in the 2.5 and 5% treatments. A type of breakdown and loss of pigmentation occurring in McIntosh and Stark apples stored in 100% nitrogen is described. Lastly, it was noted that Golden Russet apples developed superficial scald when stored for prolonged periods in carbon dioxide.

Finally, fruits affected with physiological disorders were found to have the following characteristics: (1) high rate of respiration, (2) high rate of moisture loss, (3) low acid content, (4) low total solids, (5) low osmotic pressures, and (6) increased permeability to water and electrolytes.

ACKNOWLEDGMENTS

In major part these studies were undertaken under the direction of Dr. G. W. Scarth to whom grateful acknowledgment is extended for his interest and help at all times. Appreciation is expressed to Professor J. G. Coulson and Dr. R. D. Gibbs for their particular help in the pathological and biochemical phases of the work, respectively.

The author is further indebted to Dr. W. S. Blair, Superintendent of the Kentville Experimental Station, and Mr. M. B. Davis, Dominion Horticulturist, for granting special facilities.

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Excerpts from the preface of this book summarize very neatly some of the author's objectives which, within the text, have been very adequately realized. "It is the novice to whose needs this book is directed. It is hoped that he may be furnished with a smoothly working combination of experimental data and statistical method. . . . . . It is a fundamental belief of the author that statistical method can be used competently by scientists not especially trained in mathematics. . . . . . Small sample methods are prerequisite in most biological data. For that reason, they are introduced at the start. The theory of large samples received scant attention. . . . . Fundamentally statistics is a mode of thought. Biometrics is a delineation of living things."

In view of the many recent developments in the field of statistics applied to experimental biology, it is encouraging to find an author who not only refuses to be deluged by the frequency and apparent complexity of these developments, but calmly and very effectively reduces them to a very few simple principles. The mistake is not made of treating recent ideas as necessarily belonging to a more advanced stage of development. Wherein these ideas cut across and are in advance of the old ones, the latter are either relegated to an inferior position, or are discarded entirely. The classical theory of large samples is regarded for the first time in an elementary text as a special case of the more complete theory which deals with samples of all sizes. The correlation coefficient is no longer regarded as the statistician's idol. Its limitations are clearly pointed out and the discussion of it relegated to a position inferior to that of the more substantial linear regression coefficient. The approach to the theory of linear regression is one of the neatest that has yet appeared in any statistical text.

As would be expected in a modern text, the analyses of variance and covariance occupy a prominent position, and throughout the discussion of these topics, the intimate relation between statistical ideas and experimental design, is emphasized. The analyses of variance and covariance are introduced, not as a new and distinct phase of the statistical method, but as an integral part of the whole. This is as it should be; and thus we find the term variance referred to at the very beginning of the discussion of tests of significance, and the correlation coefficient is defined at once as the ratio of covariance to the geometric mean of the variances of the variates being correlated. In this way the student is fully prepared for the discussions that follow.

Two excellent chapters discuss experiments with attributes and enumeration data. These will be found very helpful to those who have had difficulty in following through the reasoning in various applications of the Chi-square tests.

A chapter on individual degrees of freedom lays the foundation for the understanding of the discussions in more advanced texts and papers, of the principles of confounding in experimental design. This chapter follows

very logically after a discussion of methods of fitting curved regression lines, with particular emphasis on the method of orthogonal polynomials.

Taken as a whole this book is a very fine effort. While elementary in tone and exposition, it covers a wide field, and will be found of great value not only to teachers of modern methods, but to those who are endeavouring to learn, and to apply these methods to their everyday research problems in biological science.

—C. H. GOULDEN.

IMPERIAL BUREAU FOR HERBAGE PLANTS.

The Imperial Bureau for Herbage Plants, Aberystwyth, Great Britain, has recently published three very excellent bulletins on the subject of forage crops seed production.

Bulletin No. 22, *Technique of Grass Seed Production at the Welsh Plant Breeding Station*, presents a complete and comprehensive description of the methods employed by the Aberystwyth station in the work of seed production from bred strains. The very adequate manner in which all the various stages in the program of developing these strains is outlined will be of much interest and assistance to all engaged in work of a similar nature, irrespective of the place or conditions in which such work is being done. All who are working with grasses will find benefit in a study of its pages. The sections on field management and harvesting are of equal interest and importance to that which describes the methods followed in isolating the strains for seed production.

Bulletin No. 23, *Production of Legume Seed*, is a collection of concise, informative articles describing practical seed production methods for important legume crops in ten different countries. The articles are prepared by leaders in the field of work in each of the countries, and such important crops as, alfalfa, red clover, alsike clover, white clover, etc., are dealt with.

Bulletin No. 24, *Collection of Native Grass Seed in the Great Plains, U.S.A.*, outlines the general program of work now going on in the United States in connection with soil conservation and regrassing in the Great Plains area. Recognition is given to the value of the native grasses for this purpose, and methods of harvesting seed of the more important species are described. The need for assistance from plant breeders in selecting improved strains of these species is emphasized. The bulletin is of special interest to those in Canada who are now engaged in regrassing schemes in the Prairie Provinces.

—F. DIMMOCK.

SCIENTIFIC AGRICULTURE

Vol. XVIII MARCH, 1938 No. 7

THE TICKS OF BRITISH COLUMBIA[1]

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[Received for publication January 11, 1938]

GENERAL

In the present paper, data on the ticks occurring in the province of British Columbia are summarized. No detailed descriptions are given, since a more extensive paper is under preparation dealing with the ticks of Canada, which will be of a more technical nature, and which will include illustrations and detailed descriptions of Canadian ticks in their various stages. The present paper is more of an annotated check list of the Ixodoidea of British Columbia.

In connection with a tick survey[2] of the province, being conducted by the Kamloops laboratory, literally thousands of rodents, game and domestic animals and many birds have been examined. As a result there has been accumulated an extensive collection of tick specimens which provide a large part of the material for this paper. Through the courtesy of Professor G. J. Spencer and Dr. J. H. McDunnough the tick collections of the University of British Columbia, and the Canadian National Collection of Insects, respectively, have been placed at our disposal and have proved of great value and interest. Thanks are also extended to various collectors and individuals who have supplied interesting specimens and data. It is out of the question to list all of these contributors, but special mention should be made of Mr. Kenneth Racey, who has been most helpful and Professor G. J. Spencer, who, in addition to material of his own collecting, has permitted examination of collections of the late Mr. R. A. Cummings. Mr. Bryan Williams, Commissioner of the B.C. Game Department, and Mr. F. Kermode, Curator of the Provincial Museum, have also supplied interesting specimens from grouse and other hosts.

Anyone interested in the ecto-parasite fauna of British Columbia will be familiar with the valuable pioneer work on ticks undertaken by Dr. Seymour Hadwen. It is a tribute to his thoroughness that we are able to add so

[1] For the past eight years one of the major projects at the Dominion Entomological Laboratory at Kamloops, B.C. has been a survey of the tick fauna of British Columbia. This project was inaugurated by the late Eric Hearle in 1928, and carried on by him until his untimely death in 1934. During this period Mr. Hearle had accumulated and worked over more than 3000 specimens, collected from a variety of hosts, ranging from shrews to grizzly bears, and including a variety of birds. Just prior to his death his preliminary report entitled *The Ticks of British Columbia* was read at the 1934 Annual Meeting of the B.C. Entomological Society. Owing to the author's death soon afterwards this paper was never published, and the manuscript has remained from that date awaiting minor revisions and a further scrutiny of some of the material. Since 1934 many additional data and specimens have accumulated at the Kamloops laboratory. Most of this new material has been worked over during the past two winters by Messrs. G. Allen Mail, J. D. Gregson, and G. P. Holland. The report as now presented remains largely in its original form, with the exception of minor revisions to the notes on tick-borne diseases, and further data on specimens examined by the present laboratory staff.
—A. GIBSON.

[2] Assistants at the Kamloops laboratory who have done much of the field work in this project include I. McT. Cowan, 1929; H. Mobley, 1930; the late R. T. Turner, 1931 and 1932; D. Cameron, 1933; T. K. Moilliet, 1931 to 1936, and J. D. Gregson, 1933 to date. Others who have helped are E. R. Buckell, A. A. Dennys, W. Downes, R. Glendenning and Ralph Hopping.

few new records for the province. Dr. Hadwen's published records appear mainly in the Reports of the Dominion Veterinary Director General, particularly those for 1912 and 1915, a few in the proceedings of the B.C. Entomological Society, and some important papers in *Parasitology*, these together forming the most important contribution yet made to our knowledge of Canadian ticks. Also of value is the more recent work of Dr. Bruce (2) which has added much to our knowledge of tick paralysis. The papers of Dr. J. L. Todd (22, 23, 24, 25 and 26) in the Canadian Medical Association Journal must not be overlooked in this connection. The only attempt at gathering together under one cover fairly complete data on Canadian ticks is that of Dr. C. G. Hewitt (13) whose paper, "A Contribution to a Knowledge of Canadian Ticks", was published by the Royal Society of Canada in 1915. It is indispensable to the student, but is not readily accessible, and, of course, in more than twenty years a great deal has been added to our knowledge of the distribution and disease-carrying propensities of ticks.

Buckell (3) in his paper dealing with ticks and parasites of game animals, indicates one phase of the importance of ticks, and shows why all who are sportsmen should be interested in tick investigations. Those who have given it close attention are satisfied that the periodic dying-out of rabbits is very possibly due to tularaemia, a tick-borne disease carried by the rabbit tick (*Haemaphysalis leporis-palustris* Packard) and other species. The various grouse and other ground game birds show a similar fluctuation from abundance to near extinction in some districts, and Greene and Shillinger (8) in Minnesota have shown that the same disease is often responsible. The habits and haunts of these game birds render them particularly liable to become infested by the rabbit tick, the bird tick (*H. cinnabarina* Koch.) and several other species. *Ixodes auritulus* Neumann is especially a culprit at the coast, and our tick survey has shown that a large proportion of birds in some districts in the interior may be infested with the first two mentioned species. Tick-infested grouse have been found dead in districts where the birds were markedly decreasing, and there seems little doubt but that tick-transmitted diseases are among the most important factors influencing the fluctuations from abundance to scarcity.

As to larger game, such as deer and moose, a number of examinations in the case of the former have shown heavy infestation with the winter tick *Dermacentor albipictus* Packard, in the winter and very early spring months, and *D. andersoni* Stiles is undoubtedly an important factor in March and April. Dr. Bruce has shown that heavy tick infestation has been followed by death in the case of mule deer; Bradshaw (1) reports the death of moose from ticks, and there is but little doubt that great losses are sometimes occasioned. Cases of deer having numerous pus pockets have been received by the Kamloops laboratory from the surrounding areas. In one of these cases a bacterium was observed which proved fatal to laboratory animals. Whether this organism is tick transmittable is yet to be determined.

In 1932, Wallace (27), Thomas (21) and associates in Illinois, and in 1933 and 1934 Fenstermacher (6, 7) and associates in Minnesota, described a bacterial disease of moose transmitted by the winter tick, *D. albipictus*

Packard. In the latest reports on this disease, similarities to tick paralysis in British Columbia are stressed. A disease is known to be very prevalent in moose in Canada from Northern Alberta and the Maritime Provinces and to cause extremely heavy losses. In 1935, a dead moose, heavily infested with ticks, was reported from Upper Nechako Valley. Later in the same year ticks were received from Hulatt that proved infective and fatal to rabbits, and which on microscopic examination were seen to be laden with bacteria. The disease, presumably attributable to these bacteria, and which to date has not been diagnosed, is decidedly a factor to be reckoned with in game conservation, since it could soon decimate the moose population if it became well established. Unfortunately, the very factor of great increase in game, as is at present noticeable in deer and moose in this province, is apt to augment the dangers from disease.

The Rocky Mountain goat, with his long shaggy coat, is particularly apt to pick up large numbers of ticks, and Buckell (3) described most interestingly his first-hand observations on the worry and annoyance caused by *D. andersoni* Stiles to this particularly fine game animal.

Our own observations at Banff indicate that Rocky Mountain sheep are also very seriously worried by this same tick, and we have on several occasions noted dropped engorged ticks on the bedding grounds, and also spent females with their great masses of eggs. Since these have rarely been noted in nature, it is of interest that in the cases we observed the females had crawled under flat rocks to oviposit.

Unfortunately, there are extant very few records of the ticks infesting the main fur-bearing animals in the province, most of the collecting by the Kamloops laboratory staff having been from the commoner "pest" rodents, such as groundhogs and Columbian ground squirrels. Nearly all the weasels we have taken have been infested, and, in one case, there were nearly 250 ticks (*Ixodes texanus* Banks) on the neck and base of the skull of one of these animals. Specimens of this same tick have also been received from domestic mink on Vancouver Island. Undoubtedly, marten, fisher, and others of the more valuable fur-bearing animals are affected by ticks. Our observations of these animals, however, have been limited, since we are largely dependent upon the interest of trappers for the securing of tick specimens.

Losses from ticks among domestic animals are quite severe at times. Reports to the Kamloops laboratory indicate a great deal of trouble among horse ranchers, from the winter tick, *D. albipictus* Packard, almost every winter. Cameron and Fulton (4) report that in Saskatchewan, out of 150 head of live stock one farmer lost 63 head of cattle and 44 head of horses as a result of infestation with *D. albipictus* Packard. Horses normally appear to be especially favourite hosts among domestic animals, as far as this tick species is concerned. Cattle are much less attacked by this tick, but suffer along with sheep from tick paralysis caused by *Dermacentor andersoni* Stiles. Recent outbreaks in individual cattle ranches in British Columbia have involved, on two occasions 100 and 200 animals. The mortality in these two instances was 60 and 13 per cent, respectively.

As far as man is concerned there are only two species of ticks that are abundant in the province that attach readily, and that are a really noticeable pest, although many other species might occasionally attach as

accidental parasites. One of these, the coast tick, *Ixodes ricinus* Linneaus, has of late been the cause of considerable annoyance to residents in the vicinity of Victoria, B.C. and Vancouver, B.C. The tick is a common pest on pet dogs and readily attaches to humans, often causing sore, slow-healing ulcers. The other, the Rocky Mountain wood tick or paralysis tick, *Dermacentor andersoni* Stiles, is by far the most important species in British Columbia, or for that matter in North America, since it is a serious disease transmitter, especially of Rocky Mountain spotted fever and tularaemia. The former is potentially serious from a public health viewpoint, and during the last season (1936) appeared in two cases at Hedley, the first records for B.C. At the same time there occurred two cases at Manyberries, Alberta, one of which proved fatal.

Tularaemia, while a disease of some rarity, may be quite severe. In 1931, Dr. Ootmar (18) determined a positive agglutination test in a resident at Kootenay, who had contracted the disease at Banff, Alberta. The first case of human tularaemia infection in British Columbia occurred in 1934, at Cherry Creek, Kamloops, and was described by T. K. Moilliet (15).

Human tick paralysis is at present the most serious source of danger from *D. andersoni* Stiles in British Columbia, and cases occur every year in the interior dry belt, there being records at the Kamloops laboratory of over 150 such cases. These data are necessarily incomplete, since many cases occur which are never attended by doctors. A number of deaths among children have occurred, but there is now little excuse for such unnecessary fatalities, as people become educated to recognize early symptoms of the trouble. The disease is at present (1937) under investigation at the Kamloops laboratory.

During 1933 a most interesting outbreak of relapsing fever, suspected to have originated from tick bites, occurred in the Kootenays. Doctors Palmer and Crawford (19) reported on the outbreak, and Hearle (11) discussed the matter with special reference to the vector implicated. In 1935, Herms and Wheeler (12) implicated a new species of tick, *Ornithodorus hermsi* Wheeler, as a vector of relapsing fever. In 1936 there occurred near Vernon, B.C., two human cases which showed characteristics suggesting relapsing fever. It is highly probable that this tick, *O. hermsi* Wheeler, not yet reported from Canada, may be present in British Columbia, and if so be a possible vector of diseases to date not satisfactorily diagnosed.

CONCISE LIST OF IXODOIDEA KNOWN OR THOUGHT TO OCCUR IN BRITISH COLUMBIA

Super-family *IXODOIDEA*.
- Family ARGASIDAE (soft ticks).
  - Genus *Argas*.
    - *Argas persicus* Oken.
  - Genus *Ornithodoros*.
    - *Ornithodoros megnini* Duges[1].
    - " *turicata* Duges[2].
    - " *hermsi* Wheeler[3].

[1] Almost certain to occur, at least in south-eastern British Columbia as recorded from Alberta and Montana.
[2] Probably occurring in the Kootenay district; nearest record Idaho.
[3] Possibly occurring in British Columbia; only recently discovered, and stated to be widely distributed in the Sierra Nevada and San Bernardino ranges in California at an elevation of 5,000–8,000 ft.

Family IXODIDAE (hard ticks).
Genus *Ixodes.*
Ixodes angustus Neumann.
" *auritulus* Neumann.
" *dentatus spinipalpus* Nuttall and Hadwen.
" *hexagonus* Leach.
" *hexagonus* var. *cookei* Packard (rugose form).
" *kingi* Bishopp[4].
" *marxi* Banks.
" *pratti* Banks[1].
" *putus* Cambridge.
" *ricinus* Linneaus.
" *ricinus* var. *scapularis* Say.
" *signatus* Birula.
" *texanus* Banks.
Genus *Haemaphysalis.*
Haemaphysalis cinnabarina Koch.
Haemaphysalis leporis palustris Pack.
Genus *Dermacentor.*
Dermacentor albipictus Packard.
" *albipictus* Vancouver Island form.
" *andersoni* Stiles.
" *variabilis* Say[4].

Erroneously recorded for B.C.: *Dermacentor occidentalis* Neumann and *Dermacentor reticulatus* Neumann.

Possibly occurring, as recorded from adjacent states: *Ixodes aequalis* Banks and *Ixodes diversifossus* Neumann.

LIST OF HOSTS AND TICK SPECIES TAKEN THEREON IN BRITISH COLUMBIA

(Except where specified these records refer to adult ticks.)

Man.
Ixodes dentatus spinipalpus Nuttall and Hadwen.[5]
Ixodes ricinus Linneaus.
Haemaphysalis cinnabarina Koch.
Dermacentor andersoni Stiles. Adults and very rarely nymphs.

Cattle and Horses.
Dermacentor albipictus Packard.
Dermacentor andersoni Stiles.

Sheep.
Dermacentor andersoni Stiles.

Dog.
Ixodes ricinus Linneaus.
Ixodes hexagonus var. *cookei* Packard.
Ixodes ricinus var. *scapularis* Say.
Dermacentor andersoni Stiles.

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[1] Almost certain to occur, at least in south-eastern British Columbia as recorded from Alberta and Montana.

[4] Probably occurring in the Kootenay district; recorded from Montana; Cooley gives distribution for *Ixodes kingi* Bishopp, from Canada to California.

[5] Recorded by G. H. F. Nuttall (16).

Cat.
Haemaphysalis leporis-palustris Packard.
Bear (Grizzly).
Dermacentor andersoni Stiles.
Deer (mule).
Dermacentor albipictus Packard.
Dermacentor andersoni Stiles.
Deer (coast).
Ixodes ricinus Linneaus.
Dermacentor albipictus Packard. Vancouver island form.
Fox (domestic silver).
Ixodes hexagonus var. *cookei* Packard.
Coyote.
Dermacentor albipictus Packard.
Hare.
Haemaphysalis leporis-palustris Packard. All active stages.
Rabbit.
Ixodes dentatus spinipalpus Nuttall and Hadwen.[5]
Ixodes angustus Neumann.
Haemaphysalis cinnabarina Koch.[6]
Haemaphysalis leporis-palustris Packard. All active stages.
Dermacentor andersoni Stiles. All active stages, but adults more rarely.
Raccoon.
Ixodes texanus Banks.[6]
Groundhog.
Ixodes hexagonus var. *cookei* Packard. All active stages.
Haemaphysalis leporis-palustris Packard. All active stages.
Dermacentor andersoni Stiles. Nymphs and larvae.
Packrat.
Ixodes hexagonus var. *cookei* Packard. All active stages.
Dermacentor andersoni Stiles. Nymphs and larvae.
Squirrel (various species).
Ixodes angustus Neumann. All active stages.
Ixodes dentatus spinipalpus Nuttall and Hadwen.[5]
Ixodes marxi Banks. All active stages.
Ixodes texanus Banks. All active stages.
Haemaphysalis cinnabarina Koch. All active stages.
Dermacentor andersoni Stiles. Mainly nymphs and larvae. (One record of adults).
Chipmunk (various species).
Ixodes angustus Neumann. All active stages.
Ixodes marxi Banks. All active stages.
Haemaphysalis leporis-palustris Packard. All active stages.
Dermacentor andersoni Stiles. Mainly nymphs and larvae.
Weasel.
Ixodes hexagonus Leach.[6]
Ixodes marxi Banks. All active stages.
Ixodes texanus Banks. All active stages.

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[5] Recorded by G. H. F. Nuttall (16).
[6] Recorded by C. G. Hewitt (13)

Columbia ground squirrel.
Dermacentor andersoni Stiles. All active stages but mainly nymphs and larvae.

Pika.
Ixodes angustus Neumann. All active stages.
Ixodes dentatus spinipalpus Nuttall and Hadwen. All active stages.

Vole.
Ixodes angustus Neumann.

Mouse.
Ixodes angustus Neumann.
Dermacentor andersoni Stiles. Nymphs and larvae.

Mouse (whitefooted).
Dermacentor andersoni Stiles. Nymphs and larvae.

Pocket Mouse.
Dermacentor andersoni Stiles. Nymph.

Shrew.
Ixodes angustus Neumann.

Shrew (water).
Ixodes angustus Neumann.

Eagle (Alaska bald).
Ixodes auritulus Neumann[6].

Gull.
Ixodes putus Cambridge. All active stages.

Shag (cormorant).
Ixodes signatus Birula. All active stages.

Crow.
Haemaphysalis leporis-palustris Packard. Nymph.

Jay (Queen Charlotte Island).
Ixodes auritulus Neumann. All active stages.

Jay (Stellers).
Ixodes auritulus Neumann. All active stages.

Sparrow (golden crowned).
Argas persicus Oken. Nymphs.

Sparrow (song).
Ixodes auritulus Neumann. All active stages.

Pheasant.
Haemaphysalis leporis-palustris Packard.

Grouse (Blue, including Sooty and Richardson's).
Ixodes auritulus Neumann.
Ixodes ricinus Linneaus.
Haemaphysalis cinnabarina Koch. All active stages but mainly adults and nymphs.
Haemaphysalis leporis-palustris Packard. All active stages but mainly nymphs and larvae.

Grouse (Ruffed or willow).
Ixodes auritulus Neumann.
Haemaphysalis cinnabarina Koch. All active stages but mainly adults and nymphs.
Haemaphysalis leporis-palustris Packard. All active stages but mainly nymphs and larvae.
Dermacentor andersoni Stiles. Nymphs.

[6] Recorded by C. G. Hewitt (13).

Grouse (Oregon).

Haemaphysalis cinnabarina Koch. All active stages but mainly adults and nymphs.

Haemaphysalis leporis-palustris Packard. All active stages but mainly larvae and nymphs.

Lizard (Northern alligator).

Ixodes ricinus Linneaus. Early stages.

REMARKS ON SPECIES

The ticks are divided into two families: The soft ticks, ARGASIDAE, and the hard ticks, IXODIDAE. In the former the capitulum or mouth parts are located ventrally and are not visible from a dorsal view. There are but two genera and no representatives are native to Canada but are occasionally introduced from tropical and sub-tropical regions to the south. Members of the genus *Argas* have thin flat bodies with a distinct sharp-edged lateral margin, whereas the *Ornithodoros* have thick bodies with the margin poorly defined, thick and rounded. Most of the soft ticks have habits rather similar to bed-bugs.

Three genera of the hard tick family, IXODIDAE, are native to British Columbia. In the genus *Ixodes* the anal groove runs in front of the anus, a characteristic not shared by the other genera. Also the males are very distinctive in the possession of a number of ventral plates. Ticks of the genus *Haemaphysalis* are readily characterized by the peculiar arrow-shaped appearance of the mouth parts and palpi resulting from lateral projections of the second joints of the palps. In the genus *Dermacentor* a pair of small "eye spots" are present, one on each side and at the edge of the shield. These are present in larvae, nymphs and adults, and are diagnostic for the genus as far as British Columbia ticks are concerned. They are sometimes hard to detect in engorged nymphs of *D. andersoni*, but otherwise show quite well as pale clear spots.

In the following notes on British Columbia species the merest outline of a summary is given. This will be amplified for publication in a later paper, wherein it is hoped to describe in detail and illustrate all known stages of ticks of Canada.

Family ARGASIDAE.

(a) Genus *Argas*.

(1) *Argas persicus* Oken.

This flat, soft tick, reminiscent of the bed bug in more ways than one, has only once been taken in Canada. It is normally a habitant of warmer southern regions and is quite a serious pest of poultry (and sometimes man) in the southern states, where it is commonly known as the "fowl tick" or "blue bug". To our knowledge it has only been previously taken in North America in the most southerly tier of states and never farther north than California. Our specimens were received through the kindness of Professor Spencer, and were taken by that excellent collector, the late Mr. R. A. Cummings, from golden crowned sparrow at Vancouver on May 2, 1931. These little birds have a friendly habit of coming around houses in the winter in California and could well pick up the ticks when roosting in chicken-yards, and could transport the ticks when migrating north in the spring. Four specimens examined. Nymphs.

(b) Genus *Ornithodoros.*

(2) *Ornithodoros megnini* Duges.

This thick, rather shapeless tick is a southern species commonly known as the spinose ear tick, a very troublesome pest of cattle. Due to its habit of attaching in the ears of the host for long periods, it is liable to be transported considerable distances and can evidently survive quite satisfactorily in Canada since it has been taken in southern Alberta over a period of nearly twenty years. The jack rabbit is apparently the favourite host in northern areas. Hadwen (10) recorded it in 1913, and through the courtesy of Professor E. H. Strickland, specimens taken at Lethbridge on jack rabbits in December, 1931 have been received. While no records are yet available for British Columbia, the species will almost certainly be found in the Kootenay district in southeastern portions of the province. Two specimens examined. Females.

(3) *Ornithodoros turicata* Duges.

This tick is somewhat similar in shape to the last, but differs in that it has a roughened "pebbly" integument. This is a southern species common in parts of South and Central America and as far north as California. Its habits are very similar to those of bedbugs. It has occasionally been transported and established north of its main range, and Dr. R. R. Parker has a record from a mountain camp in Idaho, the nearest actual record to British Columbia. Cases of relapsing fever, a tick-transmitted disease, of which various members of this genus are among the main vectors, lead us to suspect the presence of either this tick or the following species in the Arrow Lakes district of the Kootenays. Drs. Palmer and Crawford (19) of Trail, who report the disease, advance the opinion that *D. andersoni* Stiles may be the vector. While they may prove to be correct, the evidence available does not point that way, and we are of the opinion that an *Ornithodoros* tick has been introduced. No specimens examined.

(4) *Ornithodorus hermsi* Wheeler.

First described in 1935 by Wheeler (28), this tick has since proven to be an important vector of relapsing fever. It has been taken on numerous occasions in California from the nests of small rodents, and, being a high altitude tick, may very likely be present in British Columbia.

This tick, like other members of the genus, is not a specific feeder and will engorge readily on various species of animals including mice, monkeys and man.

(c) Genus *Ixodes.*

(5) *Ixodes angustus* Neumann.

This small brown tick is one of the commonest British Columbia species, especially in the coast district. It also occurs in the interior (Vavenby), but is there largely replaced by *Ixodes marxi.* Squirrels appear to be the favoured host, but a large variety of other small rodents are also utilized to a lesser extent. An interesting point discovered by Dr. Hadwen, who worked out the life-history in detail, is that the male is seldom found on the host but probably stays in the nest of squirrels and other rodents. The nymph and larva are very unlike the adult in certain characters of the palpi. Sixty-one specimens examined. Two males, 36 females and 23 nymphs.

(6) *Ixodes auritulus* Neumann.

This is a bird tick of remarkably wide distribution, occurring commonly on birds in the most southerly tip of South America and also in British Columbia and probably in various Pacific Coast States, according to a recent record by Philip (20). In the coast district this appears to be the commonest tick on grouse, both blue (sooty) and willow. It has been taken in all stages on an extraordinary variety of birds, but does not appear to infest rodents or other small animals. No specimens have been taken in the interior of British Columbia, and it seems to be restricted to the wet coastal area. Thirty-three specimens examined. Eight females and 25 nymphs.

(7) *Ixodes dentatus* var. *spinipalpus* Hadwen and Nuttall.

This rather distinctive species has only been taken to date in the coast district, but it does not appear to be common. Nuttall (16) has recorded it from rabbit, squirrel, and a child at Mt. Lehman, and we have recently examined specimens from pika taken at Alta Lake, B.C. by Mr. Kenneth Racey and loaned us through the kindness of Professor Spencer. Fifteen specimens examined, 3 males, 6 females, 4 nymphs and 2 larvae.

(8) *Ixodes hexagonus* Leach.

We have not been able to place this rather robust thick-legged species in any of our B.C. material, but Hadwen took it at Mt. Lehman on weasel (records by Hewitt (13)). No specimens examined.

(9) *Ixodes hexagonus* var. *cookei* Packard.

We have found this tick to occur quite commonly in all active stages on groundhogs in the interior dry belt, and Hadwen has taken it on dog at Mt. Lehman. One hundred and twenty-seven specimens examined. Twenty-seven females, 53 nymphs and 47 larvae.

(10) *Ixodes kingi* Bishopp.

This species, which resembles *pratti*, and is also apt to be confused with *cookei*, has not been taken yet in British Columbia, but has been recorded from Montana by Cooley (5). Since it has also been taken in Alberta from gopher burrows, it will probably be found in the south-eastern part of this province. We have had the privilege of examining specimens from Wyoming, the type locality, through the kindness of Dr. R. R. Parker, 1 male and 3 females; and also 2 males, 2 females and a nymph in our collection from Medicine Hat, Alta. collected by the late Mr. F. S. Carr.

(11) *Ixodes marxi* Banks.

This is usually considered to be an eastern tick, but we have found specimens that agree very closely with it in the Kamloops and Nicola districts and North Thompson valley. It has been taken almost entirely on pine squirrel, and takes the place of *angustus* on squirrel in the interior, although the latter also occurs, but sparsely. Two hundred specimens examined: 12 females, 81 nymphs and 107 larvae.

(12) *Ixodes pratti* Banks.

This is a species about which much confusion exists. When making his description Banks apparently had at least two species (*pratti* and *kingi*)

before him. In the Nuttall and Warburton monograph (17), Part 2, the description and illustration designated as *pratti*, female, were apparently based on a specimen of *Ixodes kingi* Bishopp, erroneously identified as *pratti* by Banks. Bishopp states, however, that the type specimen of *Ixodes pratti* Banks has definite auriculae (ventral processes on the capitulum), and this at once differentiates the species from *kingi* and most others with which it has been confused. So far no specimens agreeing with *pratti* have been taken in British Columbia, but Dr. R. A. Cooley has recorded it from Montana and Dr. S. Hadwen records it from cat and horse in Alberta; the latter records, however, are more than likely to be really of *Ixodes kingi* Bishopp based on Nuttall and Warburton's key. Further collecting may reveal it in the southeastern portion of the province.

(13) *Ixodes putus* Cambridge.

This is a rather unusual species found on large sea birds, usually attached to the head and neck. It has an extraordinarily wide distribution in Europe, Asia, Australasia and America. There is one previous Canadian record for British Columbia, and one in Eastern Canada. We have examined a female, nymph and larva in the University of British Columbia collection taken by Professor Spencer at Tofino on August 14, 1926, from a dark sea bird. Three specimens examined: 1 female, 1 nymph, and 1 larva.

(14) *Ixodes ricinus* Linneaus.

This is the common tick attacking man in the coast district. When flat it is a very distinctive species, especially the adult female, being a rich red with a reddish-brown shield and legs. It has in recent years greatly increased in numbers, and numerous complaints have been received from Vancouver Island and the mainland from Vancouver to Powell River, B.C. Mr. R. Glendenning has sent us specimens from Agassiz, B.C. and informs us that it is very common in the Agassiz and Chilliwack districts, and constitutes a pest to humans in the spring months. As Gregson (9) has indicated in his paper, the early stages feed on lizards. This is similar to the species occurring abundantly in parts of California as noted by Jellison (14), and recorded as *Ixodes ricinus* var. *californicus* Banks. We do not consider this varietal name warranted, on account of the variation known to exist in European *ricinus*. Specimens of the latter (through the courtesy of Dr. R. R. Parker), and Californian specimens (through the courtesy of Mr. Jellison) have been compared with a very large series from British Columbia, and it was found that variations wipe out the slight difference upon which the varietal name was based. *Ixodes ricinus* is an important vector of certain diseases affecting livestock, especially sheep, in Great Britain, but no trouble in this connection has been noted in this province. Seventy-three specimens examined: 30 males, 37 females, 5 nymphs, and 1 larva.

(15) *Ixodes ricinus* var. *scapularis* Say.

This tick has been recorded from Vancouver by Dr. Hadwen and a specimen has been received from Professor Spencer. This was taken on a dog at Shaughnessy Heights, Vancouver. The outstanding characteristic that readily differentiates it from the true *Ixodes ricinus* Linneaus is that the shield and legs are black. One female examined.

(16) *Ixodes signatus* Birula.

This species somewhat resembles *putus* and also is restricted to sea birds, but is only rarely found on them other than the cormorant. There have been no previous Canadian records, but we have examined females and a large series of nymphs from Brandt's cormorant, *Phalocrocorox pexicillatus* taken by Professor Spencer at Tofino, V.I. on August 5, 1926. In one of the females the porose area was a little like that in *unicavatus*, but other characters indicated *signatus*, in which we place it. This is another species of extremely wide distribution, as is *putus*. Twenty-four specimens examined: 2 females and 22 nymphs.

(17) *Ixodes texanus* Banks.

This was recorded by Dr. Hadwen from raccoon in the Fraser valley, and in the Bella Coola district in the winter, and also from squirrel. We have taken large series in the Kamloops and Nicola district on weasel and squirrel In one case nearly 250 ticks were found on the neck of a weasel. Two hundred and forty-two specimens examined: 5 females, 153 nymphs, 84 larvae.

(d) Genus *Haemaphysalis*.

(18) *Haemaphysalis cinnabarina* Koch.

This is the most common bird tick of Canada, and is a species sometimes causing considerable losses to turkey raisers. It has been found very abundantly on ground game birds in the interior of the province during our tick survey and is particularly troublesome on grouse. It can be separated from the next species by its brighter red-brown colour and by the less acute projection of the second palpal segment; also, *cinnabarina* lacks the small auriculae noted in all stages of the other. It undoubtedly is responsible for the death of many birds, either directly or on account of disease transmission. A fatal case of human tick paralysis at Kamloops was attributed to this species by Todd, but probably in error. Doubtless *andersoni* was attached as well. One hundred and two specimens examined: males 39, females 8, nymphs 10, larvae 45.

(19) *Haemaphysalis leporis-palustris* Packard.

This, in point of numbers, is probably the most abundant tick in Canada. It is distributed almost universally throughout the Dominion. While rabbits are the main host, it also attacks ground-inhabiting birds, such as grouse and meadow larks. Apart from its importance in causing the death of ground game birds, it is a serious factor in the transmission of Rocky Mountain spotted fever and tularaemia from animal to animal, although it does not attach to man, and therefore is not a direct transmitter of human disease. Very large series of all stages examined. Total nearly 2000.

(e) Genus *Dermacentor*.

(20) *Dermacentor albipictus* Packard.

The winter or moose tick is one of the commonest and most widespread of Canadian species. Many recent writers have left the impression that it is mainly a Rocky Mountain tick. This is quite erroneous, since it occurs abundantly from coast to coast, and we have examined or have

records of specimens from almost every province in the Dominion. This is one of the few ticks occurring in America in which all stages remain on the host, instead of dropping between moults. Horses and the larger wild game such as moose and deer are preferred hosts, and man is not attacked. Large mortality is attributed to this tick or diseases transmitted by it. The larval ticks attach in September, and the ticks are on the hosts throughout the winter.

It has been observed that the Vancouver Island form of *Dermacentor albipictus* Packard matures much earlier than that found on the mainland. There are also minor morphological differences such as in the number of goblets in the spiracles. A large series is now being studied and if it is considered that the island form is a new variety, a full description will be published in the near future. Six hundred and sixty-six specimens examined: 71 males, 126 females, 169 nymphs, and almost 300 larvae.

(21) *Dermacentor andersoni* Stiles.

This is the most important of all Canadian ticks and is a serious human health menace. Our records are very extensive for this species, and we find that the distribution is much wider than formerly supposed. Early stages almost invariably attack small rodents, depending on the species most abundant in the locality. Adults also are sometimes found on rabbits, squirrels or Columbia ground squirrels, but mainly feed on the larger animals such as cattle, horses, and man.

The danger from this tick of tick paralysis, spotted fever, tularaemia, and other diseases is so well known that we need not again stress the importance of the species. We have taken larvae from June to as late as November 27, but they are mainly found in July. Adults occur on the host mainly from March to May. Occasionally specimens are found as early as February or as late as November, and we have a number of records in June, July and August, but this is exceptional. One thousand two hundred and thirty-seven specimens examined: 214 males, 251 females, 247 nymphs, and 525 larvae.

(22) *Dermacentor variabilis* Say.

This is the dog tick. It replaces *andersoni* as a pest of man, particularly in Saskatchewan and Manitoba. It is superficially quite like the last species. We have no British Columbia records as yet, but it has been recorded in Montana by Cooley and may possibly occur in the south-eastern part of the province. Hadwen has worked out the life-history in detail.

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS*, HBN., AND THE PHYSICAL FACTORS AFFECTING THEM[1,2]

I. INTRODUCTION. HISTORY AND IMPORTANCE OF EUROPEAN CORN BORER IN SOUTHERN ONTARIO. METHODS OF STUDY.

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[Received for publication January 12, 1938]

Comparatively little is known regarding the critical periods of flight, oviposition and larval establishment in the life cycle of the European corn borer, and much less is known regarding the influence of physical factors on these phenomena. The present systematic field study was conducted during the past ten years to learn the characteristics of these periods, their seasonal and daily variations, and the physical factors, if any, influencing or controlling them. The importance of this detailed knowledge is apparent, but may be emphasized by the following statements.

Larval abundance of, and therefore crop damage by, the European corn borer is largely determined within the periods under discussion, and a biological study in relation to physical or climatic factors shows what has happened in the past and gives an insight as to what may be expected in the future under the same or different conditions.

This information largely governs the development of experimental and practical control methods by means of chemicals or fungus diseases directed against the adult, egg or larva. Marchlewski (8) pointed out as late as 1930 that in order to use chemicals against the moth or larva the biology must be thoroughly known before a suitable control method could be developed, and that, unfortunately, this knowledge was then inadequate from a practical point of view.

It is also desirable to know whether a season is favourable or unfavourable to the increase of the European corn borer when evaluating the success or failure of the only control measure practised on a large scale, namely, that of the destruction or "clean-up" of corn debris from season to season. Caesar (3) stated in 1929 that we could not interpret results of clean-up operations correctly without knowing the effect of the season upon the insect itself.

The work herein reported was carried out at Chatham, Ontario, in the seed corn producing area of Kent and Essex counties. The area is

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[1] A thesis submitted to the Graduate School, University of Minnesota, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2] This subject will be discussed in five articles during consecutive months, in this journal. Subsequent articles will be: II. The flight of the European corn borer. Annual cycle of flight. Daily rhythm of flight. Flight to light trap. III. Flight of European corn borer. The influence of the physical factors upon flight. IV. The oviposition and establishment periods. Annual cycle of oviposition. Daily cycle of oviposition. Flight and oviposition. Egg mortality and survival. Larval mortality and survival. V. The seasonal characteristics of flight, oviposition and larval establishment. The variations and effects of seasonal climate. The factors causing fluctuations in borer populations. Summary. Acknowledgments.

[3] Entomologist in Charge.

of special interest in that during the years 1925 and 1926 the European corn borer damaged the corn crop to a greater extent than in any other locality since its introduction into North America. It is quite probable also that this infestation was greater than has occurred at any time during the history of the insect and within any locality in its known geographical range.

An attempt has been made to retain throughout a broad viewpoint and to correlate the observations and conclusions made in this study with the fundamental problems of insect biology. Where necessary and desirable, these have been pointed out and discussed.

The work was planned and originated by the author in 1926. Since 1927 it has been carried out by the author and various assistants, to whom due credit is given in the section of "Acknowledgments".

CHARACTERISTICS AND DESCRIPTION OF LOCATION OF WORK

Geographical Location

Chatham, Kent County, Ontario, is located at latitude 42° 23′ N. and longitude 82° 12′ W. Its elevation is 595 feet above sea level. It is situated in the southwestern peninsula of southern Ontario on the Thames River, 15 miles east of Lake St. Clair, 12 miles northeast of Lake Erie, and 55 miles northeast of the Detroit River.

Topography

The environs of Chatham, and most of the seed corn producing area surrounding it consist of flat, level plains which were formerly glacial lake bed. At some points along the lake shores the land is dyked.

Climate

The climate of the region is characterized by warm, humid summers, with comparatively mild, more or less open winters. The mean normal monthly temperatures and total mean precipitation, compiled from the records of the Meteorological Service of Canada, are given in Table 1.

TABLE 1.—MEAN NORMAL TEMPERATURES AND TOTAL MEAN PRECIPITATION AT CHATHAM, ONTARIO

Month	Mean normal temperatures in degrees F.	Total mean precipitation in inches	Number of years of observation
January	24	2.19	48
February	22	2.03	48
March	32	2.13	48
April	45	2.29	48
May	56	2.97	48
June	66	2.64	48
July	70	2.81	48
August	68	2.50	48
September	62	2.64	48
October	50	2.47	48
November	38	2.44	48
December	29	2.26	47
Yearly mean	47	29.37	

Figure 1 shows the mean thermohyetic conditions for Chatham.

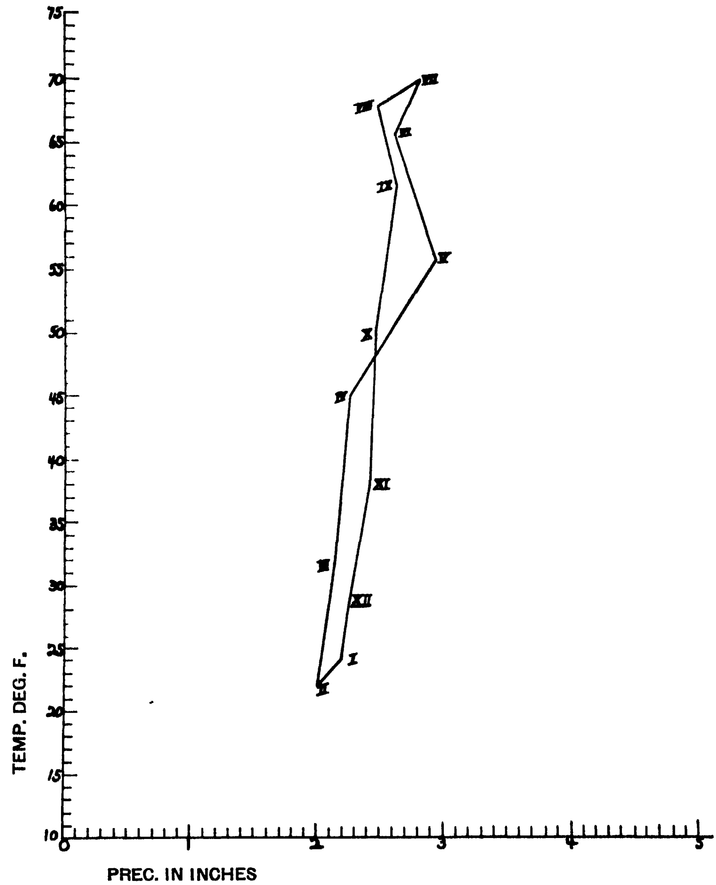

FIGURE 1. Monthly mean thermohyetic conditions, Chatham, Ontario. Based upon 48 years' records.

Original Plant Associations

The area surrounding Chatham, including Kent and Essex counties, lies within the boundaries of the deciduous Forest Formation. Transeau (15) who made a study of the botanical features of the area states that the region was originally dominated by a series of plant associations from Phragmites marsh to swamp forest. The swamp forest of the area was dominated by such trees as American elm, white and black ash, and red and silver maple. The secondary species include pin and swamp white oak, basswood, cottonwood, sycamore, shagbark, and pignut hickory.

Corn and Corn Production

The total corn crop of Ontario in 1935 was 492,509 acres, valued at $12,595,245. Over a period of years the acreage and value have been greater, as in 1922 the acreage was 703,837 valued at $26,262,267.

Corn is an essential factor in the agriculture of the province, being grown mainly for fodder and for seed (husking corn). Almost the entire crop of seed or husking corn is grown in the southwestern portion of the province in the Counties of Essex, Kent and a portion of Lambton, which also produce considerable fodder corn. Chatham is situated in the centre of this area, which is the "corn belt" of Ontario.

The total area planted to corn in these three counties during 1935 was 152,792 acres valued at $3,558,802. Over a period of years the acreage and value run much higher, as may be seen from the figures presented later in regard to corn borer damage.

THE HISTORY AND IMPORTANCE OF THE EUROPEAN CORN BORER IN THE REGION

History

The European corn borer was first discovered in Ontario near Lorraine Station, Humberstone township, Welland county, on August 10, 1920, and near St. Thomas in Elgin county on August 22 of the same year according to McLaine (10). The former location is about 150 miles east of Chatham, while the latter is about 70 miles east. The infestation in Elgin county extended almost to Chatham at the time of its discovery and by 1922 the borer was found in most of the area embraced by the three counties of Kent, Essex and Lambton. By 1924 the percentage of corn stalks infested was 24 in Kent county, 11 in Essex county, and a trace of infestation in Lambton county.

Corn Acreage Reduction and Corn Borer Damage

The borer rapidly increased in numbers in this area and other parts of the province, until in 1926 it ruined the entire corn crop of practically the whole of Essex and Kent counties. Since 1926, the borer has not done a very great amount of commercial damage, but continues in such numbers that it is a very great potential danger to the corn industry. The damage in 1925 and 1926 was the worst ever recorded in the history of the borer either in Europe or America.

The corn borer entered the seed-corn growing area of Ontario at a period when the corn acreage was gradually being reduced mainly because of the low price of corn relative to other crops in 1921, 1922, 1923, 1925 and 1926. Another factor which played some part in the reduction of acreage was the shift to a more intensive agriculture within the region as shown by increased plantings of tobacco and truck crops.

There is no doubt, however, that the corn borer and its damage was largely responsible for and accelerated the already apparent decline in acreage between the years 1924 and 1927 in the seed-corn growing area. Figure 2 illustrates the relationship between corn borer damage and corn acreage reduction.

From Figure 2 it can be seen that a reduction in acreage both in Kent and Essex counties and throughout the Province took place at the time the borer was becoming established. The greatest reduction took place in 1927 following the destruction of the crop of 1926. When the crop of 1927 and later years was not damaged to any extent, the acreage began to increase. Throughout Ontario, as a whole the reduction began somewhat earlier, and naturally was not as severe as in the local area. The

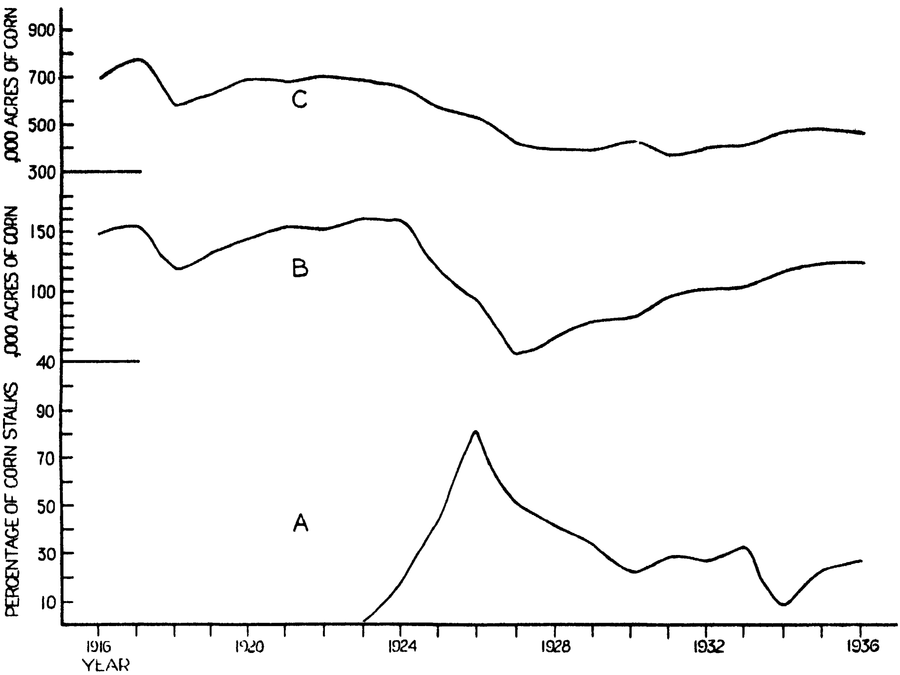

FIGURE 2. Relation between corn borer damage and corn acreage reduction in Essex Kent counties and in the Province of Ontario. A. Average per cent stalk infestation by borer for Kent and Essex counties. B. Total corn acreage, Kent and Essex counties. C. Total corn acreage, Province of Ontario.

curve for Ontario probably shows the effect of the influence of other economic factors to a greater extent than that for Essex and Kent counties, as in the major portion of the Province, the corn borer was not a factor as it either was not yet present or not abundant enough to cause commercial damage.

THE LIFE HISTORY AND CHARACTERISTICS OF THE EUROPEAN CORN BORER IN SOUTHERN ONTARIO

Life History.

The life history of the European corn borer in Ontario has been reviewed in some detail by Crawford (5), Spencer (12) and Stirrett (13). The insect as found in the area is of the univoltine type, as in western New York, Ohio, Michigan, Indiana and other midwestern states. In general, the overwintering larvae pupate early in June and the moths begin to fly during the last few days in June and in July. Oviposition, hatching and larval establishment take place in July, but in some years may extend into early August. Larvae become full-grown within the corn stalks about the last of August and first part of September. With the approach of cool weather they enter hibernation within the stalks.

The average winter mortality found among larvae at Chatham is from 6 to 9%. In other portions of the province the winter mortality may be much higher as shown by Stirrett (14).

Host Plants

Corn is the only primary host of any importance in Ontario and it is very rare indeed to find the borer infesting any other plant.

Parasites and Predators

No egg or larval parasites or predators have been observed by us in our experimental plots during the ten years' work. The same is true of fungus and bacterial diseases. Although imported parasites have, in the past, been liberated in the district, the degree of parasitism found from an annual survey is less than 1% for the entire region. In other parts of the province, namely, in the vicinity of Belleville, imported parasites have killed as high as 30% of the larvae in certain fields. Belleville is approximately 350 miles east and north of Chatham.

OUTLINE AND DISCUSSION ON METHODS OF STUDY

A detailed quantitative field study of the flight of moths has been made at Chatham, Ontario, during the years 1927 to 1936, a period of ten years. The corn plot studies of flight have been supplemented by light trap catches of the moths during the seasons of 1931 to 1936 inclusive and by supplemental corn plots during the years 1929, 1932, 1933, 1934 and 1935.

Field studies on oviposition have been carried on during the seasons from 1927 to 1936 inclusive, while field studies on establishment have been made for the years 1928 to 1936 inclusive. Each year a plot of corn about 2½ acres in extent was grown for these studies. The corn variety used throughout the work was Wisconsin No. 7, a white dent variety of commercial importance in the district surrounding Chatham.

The corn plots of 1927 and 1928 were grown at a different location from those of 1929 to 1936. The plots in these two groups of years were grown about three miles apart. This change in location was unfortunate, but necessary. The plots from and including 1929 were grown on the same location. The plots received the standard field treatments in regard to fertilization, planting, cultivation, hoeing and were located adjacent to Chatham within the market garden and farming district.

Fortunately, there was a good crop each year well up to average for the district.

For convenience of description, the remainder of the methods used will be divided under three headings: methods in study of flight, methods in the study of oviposition and establishment, and the measurement of the physical factors.

Methods of Study of Flight of Moths

Field Plots. Standard Plot "A"

Within the larger plot of corn a flight plot and an oviposition and establishment plot were measured and staked. The flight plot was 80 × 200 feet, or an area of 16,000 square feet in the years 1929 to 1936 inclusive. Such an area contained about 27 rows of corn, 200 feet long.

During the first two years a study of the variation in size of plots was tried out. In 1927, the flight plot size was 40 × 240 feet or 9,600 square

feet, while in 1928 the size was 40 × 120 feet, or 4,800 square feet. It was decided that a larger plot could be handled, and consequently the 1929 plot was increased to the standard size followed during all years since, *i.e.*, 16,000 square feet. In the records used in this paper the actual number of moths captured during 1927 are multiplied by 1.67, while those of 1928 are multiplied by 3.35 to bring the records to the basis of size of plots for the other years.

Studies on the fluctuations in numbers of an insect are possible only by the adoption of a definite quantitative method which allows the investigator to follow the gradations of the species in question year after year.

Observations were made each hour of the night during the flight season over the plot for a period of fifteen minutes, to determine the number of moths in the plot. Observations were continued each night until one or no moths were secured in the plot. The first five minutes of each hour were used in recording the physical factors according to the directions given below. After these were secured a search was made of the plot for corn borer moths for a period of fifteen minutes, then the plot was vacated until the next hourly observation. The moths were observed by slowly walking up and down the corn rows and illuminating the plants or moths in flight by use of a four-celled flashlight. After some practise, moths could readily be seen in flight or resting on the corn plants. Adult corn borers fly rather slowly in contrast to many of the other Lepidoptera. Their light colour also helps in readily distinguishing them while flying. Without some practise they might be confused in flight with *Haematopsis grataria* Fabr., a geometrid moth of the same size as the corn borer adult. It is also light in colour, being a pinkish-yellow. The male and female corn borer moths can also readily be differentiated by their character of flight; the female, somewhat the larger, is lighter in colour and flies much more regularly or steadily than the smaller, darker, swifter male.

When a moth was observed, it was caught if possible, its sex determined by squeezing the abdomen to extrude the genitalia and then killed.

It generally required the full fifteen minutes to patrol the plot. One could regulate his speed after some practise to cover the plot in the time required. If one finished the plot before the time limit, the remainder of the time was spent in repeating the observations in the plot until the time was up.

In the early years of work, each row of corn was examined; later when moths were fewer in number, three rows of corn were examined at a time.

Flight records and meteorological observations were recorded on a mimeographed record sheet. A new sheet was utilized for each hourly observation.

During the first two or three years, observations were begun on Eastern Standard time, and there was some variation in the time of commencing observations; later all observations were made in sunset time and the observations were begun exactly on time at the time indicated in the records. All records in regard to flight are given in sunset time. The records for the earliest years are given to the nearest hour, but do not vary more than twenty minutes from the time indicated.

The time at which sunset occurred at Chatham, Ontario, for the years and dates under consideration is given in Table 2. The author is indebted

to Mr. C. C. L. Gregory, Wilson Observatory, University of London, England, through Mr. Geoffrey Beall, for these calculations.

TABLE 2.—SHOWING EASTERN STANDARD TIME (P.M.) AT WHICH SUNSET OCCURS AT CHATHAM, ONTARIO

Date	Time	Date	Time	Date	Time	Date	Time
June 28	8:10	July 8	8:8	July 18	8:2	July 28	7:53
29	8:10	9	8:7	19	8:1	29	7:52
30	8:10	10	8:7	20	8:1	30	7:51
July 1	8:9	11	8:6	21	8:0	31	7:50
2	8:9	12	8:6	22	7:59	Aug. 1	7:49
3	8:9	13	8:5	23	7:58	2	7:48
4	8:9	14	8:5	24	7:57	3	7:47
5	8:9	15	8:4	25	7:56	4	7:45
6	8:8	16	8:3	26	7:55	5	7:44
7	8:8	17	8:3	27	7:54		

These average values are not strictly true from year to year, but they are not in error more than one minute if applied to any year. Sunset is taken to be the moment at which the upper rim of the sun apparently sinks below the horizon.

In comparing Sunset time and Eastern Standard time, the following are the equivalents for July 12.

Sunset Time	Eastern Standard Time	Sunset Time	Eastern Standard Time
–:30*	7:36 p.m.	6:30	2:36 a.m.
:30	8:36 p.m.	7:30	3:36 a.m.
1:30	9:36 p.m.	8:30	4:36 a.m.
2:30	10:36 p.m.	9:30	5:36 a.m.
3:30	11:36 p.m.	10:30	6:36 a.m.
4:30	12:36 a.m.	11:30	7:36 a.m.
5:30	1:36 a.m.	12:30	8:36 a.m.

* —:30 means 30 minutes before sunset.

At –:30 Sunset time, it is still daylight at Chatham during the summer months. Dawn or sunrise occurs between 6:30 and 7:30 Sunset time.

If Standard time had been used each succeeding night the observations would be taken later with respect to Sunset time and an error would be introduced between supposedly parallel observations. If observations from a year with early flight be compared with those of a late one, the error would be greater.

Field Plots. Supplementary Plots. Plot "B"

In certain years, flight observations were made in plots of corn belonging to farmers in the neighbourhood. These plots were utilized on certain nights in 1927, and during the seasons 1929, 1932, 1933, 1934 and 1935. The plot areas were exactly the same as in our own standard plot "A", so that direct comparisons could be made between the plot. The observations were made in exactly the same manner as described above.

Light Trap Studies

During the years 1931 to 1936 inclusive, a light trap was operated in a farmyard one mile distant from the standard plot "A". The trap was

a deGryse (6) type trap, fitted with a 100-watt, white frosted electric bulb. The bulb was renewed frequently in order to have a fairly constant light intensity. The light was operated from April until about October 20. It was lighted each night about 6:30 p.m. The light trap catches were examined daily for corn borer moths. These were recorded according to sex. The insects were killed by the use of calcium cyanide dust deposited in the bottom of the trap. It was replenished every other day in order to keep the gas at a high and more or less uniform concentration. On certain nights several thousands of various kinds of insects have been collected in this trap.

In the flight records throughout the paper, the Standard plot is designated plot "A", while the secondary farmers' plots when used are designated plot "B". The light trap catches are referred to as "C".

Methods in the Study of Oviposition and Establishment

Definition of Larval Establishment

Larval establishment is understood to mean that after hatching the larval settle down within the host plant to a successful life of feeding and growth. To become established, the larva must continue to live and develop, at least for a period of time. Larvae hatching, entering the corn plant, and living successfully to a period just before the commencement of autumn migration are said to be established.

Oviposition and Establishment Plot

A short distance from the flight plot and within the laboratory field of corn an oviposition and establishment plot was made each year beginning with 1928. In 1927, oviposition records only were taken. The oviposition and establishment plot consisted of staked and marked corn plants upon which egg laying, hatching and establishment records were taken throughout the season. The plants for this plot were thinned so that only one plant, without suckers, was allowed to grow at any given point. The plants were 36 inches apart each way, unless, of course, a plant died or was accidentally taken out.

The plot consisted of two parts; the two outside rows of corn on each of the four sides of the plot was termed the buffer plot because it was to act as a buffer between the establishment plot proper and the corn plants in the general field. On it egg masses were observed, the eggs counted and then destroyed. The inner remaining plants were called the plot proper. On it eggs were observed, counted, marked, and continued under observation until they hatched, when the larvae were allowed to establish themselves within the plant. Thus, any larvae found on the buffer plot must have come either from the plot proper or from the corn surrounding the plot, while any larvae found in the plants of the plot proper must have come from eggs laid on the plants in this portion of the plot.

The corn stalks in both the plot proper and buffer plot were dissected and examined for established larvae between August 20 and August 22 of each year. This date is just before the early autumn migration of the borer. Any larvae found in the plants at this time whether dead or alive were said to have become established. It was only very rarely that dead larvae were found. Only lárvae found in the plot proper and the inner

row of the buffer plot were said to have become established and used in the calculations of establishment.

The oviposition and establishment plots varied somewhat as to the number of individual plants which they contained each season. The numbers in the plot for each year are as follows:

1928 — 176 plants	1933 — 143 plants
1929 — 191 plants	1934 — 144 plants
1930 — 122 plants	1935 — 132 plants
1931 — 189 plants	1936 — 132 plants
1932 — 148 plants	

It took the services of one man at least a full morning to examine these plots and make the necessary observations.

It was intended that the plants should be examined and records taken each day during the season. However, in some years this was not possible and the observations were made every other day. They were made every day during the years 1928, 1931, 1932, 1933, 1934, 1936, and every other day during 1929, 1930 and 1935. The eggs very rarely hatch within three days and therefore no eggs could be laid, hatch and disappear before being examined.

When egg masses were found they were marked with an indelible pencil on the leaf near egg mass and recorded in a notebook according to row number, plant number, leaf number, and etc. There was very little chance of the mass becoming lost or records being confused. Sometimes when it was very hard to count the number of eggs in a mass, the counting of the individual eggs was left a day or two until embryonic development made the individual eggs more easily recognizable.

The oviposition and hatching observations were made on the morning or afternoon of the day following the flight of moths but throughout this paper, oviposition records are given under the date of the night the eggs were actually laid and not the day they were examined.

Planting Dates and Maturity of Corn

It is a well known fact expressed by numerous authors and observed and studied by ourselves on a number of occasions that the number of moths attracted to any given field of corn depends upon the maturity of corn as expressed by height of plant, date of tasselling, date of silking, and other criteria. The highest corn in any given region will attract the most moths and will, therefore, have the most eggs laid upon it. Moreover, it is well known that the amount of larval establishment is influenced by such factors as maturity of corn, growth habit, varieties, density of larvae and other factors not yet clearly defined.

In this study of the fluctuations of the number of moths flying, the number of eggs deposited, in egg mortality and in larval mortality and their correlation with the physical factors from year to year, these varying factors have been eliminated as much as possible by the use of only one variety of corn throughout the work and by planting the plots at the same or corresponding phenological time each year.

The height of corn in the plots has varied from year to year, but so have the dates of flight and oviposition, and therefore the height of corn

(maturity) from year to year would have no significance in regard to the relative attractiveness of the corn to moths on the same date. The corn height each year would, however, have a marked significance in comparing the flight or establishment as found in our plots with that found in adjacent plots in the same season.

The corn has been planted each year at the best planting date for the season and region. This date is utilized by the largest number of corn growers, and corn planted at such dates should give corn which would attract the same number of moths and have practically the same rate of establishment as the large proportion of the corn crop of the district.

The plots show the numbers of moths attracted and the same rate of establishment as the great bulk of the corn of the region for each season. They do not show the number of moths or establishment rate as found in very early or late fields. That this is so is proven by the very close relationship between the numbers and seasonal occurrence as found in our plots and that shown by light trap catches which are not influenced by the growth of corn.

One might compare the height of corn on any fixed date from year to year. However, since any such date falls at a different point in the progress of flight from year to year, it would appear more satisfactory to refer the height of corn from year to year to some relatively fixed point in the progress of flight. Accordingly, it has been referred to the apparent peak of flight.

The height of the corn in plot "A", at the time of the peak of moth flight, is given below. The height of corn is the distance from the ground surface to the upper part of the bend in the topmost leaf of a plant. The average is based on at least the measurement of two hundred plants selected at random in the plots.

Year	Date of peak of moth flight	Average height of corn in inches	Year	Date of peak of moth flight	Average height of corn in inches
1927	* July 12	18	1932	July 7	27
1928	July 16	23	1933	June 29	22
1929	July 7	12	1934	July 12	30
1930	July 8	27	1935	July 11	37
1931	July 9	31	1936	July 9	30

The tasselling and silking dates have been recorded during the past four years and are given below.

Year	Average date of tasselling	Average date of silking	Year	Average date of tasselling	Average date of silking
1933	July 16	July 29	1935	July 24	Aug. 3
1934	July 16	July 27	1936	July 16	July 30

The planting dates may also be of interest and they are as follows:

Year	Date	Year	Date	Year	Date	Year	Date
1927	June 5	1930	May 26	1932	May 31	1935	May 21
1928	June 5	1931	May 26 and 27	1933	May 23	1936	May 20
1929	June 6			1934	May 21		

The later planting dates of the first three years were brought about by seasonal conditions, but also because it was the general practise of the farming community to delay planting in order to avoid damage from the borer. After three years without much damage, the original general planting date was again taken up.

In regard to "B" plots studied, that of 1929 was an early field of sweet corn planted May 14. It was much more mature and taller than plot "A" of the same year at the time of moth flight. It was situated about three hundred yards from plot "A". The 1932 plot was also an early plot of sweet corn, two miles distant from plot "A". In 1933, plot "B" was in a field of yellow dent corn planted about June 1, that is, one week later than plot "A". It was about one-quarter mile from plot "A". In 1934, plot "B" was in a field of yellow dent corn planted May 22. It was a little less than one-quarter mile from plot "A". In 1935, plot "B" was in a field of yellow dent corn planted May 22. It was in the same location as in the previous year.

It will be noted that plots "B" for 1934 and 1935 were planted at the same time as our own plot "A".

Measurement of Physical Factors

All of the physical factors were measured within the corn field at the time of observations on flight, and for the studies on oviposition and establishment other records were secured throughout the season by the use of a recording hygrothermograph set up in the field.

It has been shown by Miller and Saunders (11) that the temperature on the upper surface of turgid corn leaves between 9:00 a.m. and 4:00 p.m. in direct sunlight is essentially the same as that of the surrounding air. In one thousand determinations they found that the average temperature on the surface of a corn leaf was 30.64° C., while that of the surrounding air at the same time was 30.58° C. It would appear, therefore, that a temperature recording instrument in the field would give a very accurate measure of the temperature being experienced, say, by eggs on a corn leaf.

Temperature

During the first year, temperature was obtained by use of a Taylor Instrument Company sling psychrometer. During the second and later years, it was obtained from a Friez thermograph placed within a standard weather bureau type shelter. At the time of night when observations on flight were being taken, the door of the shelter was left open to facilitate readings. The thermograph was checked and corrected for temperature at least once a week and generally more frequently during the flight season. The instrument within the shelter was four feet from ground surface. Temperatures throughout the paper are given in degrees Fahrenheit.

Atmospheric Humidity

In the field, this factor was determined as relative humidity by the use of a sling psychrometer during the first year and by use of a Friez hygrothermograph in subsequent years. The hygrothermograph was checked at least once a week against a sling psychrometer. It was enclosed in the same shelter as mentioned above under the heading "Temperature."

For the purposes of this paper, humidity is given in terms of saturation deficiency expressed as a vapour pressure in millimetres of mercury. This factor has been calculated for all observations from the temperature and relative humidity records by use of the nomogram for saturation deficiency determinations designed by John R. Baker (1) at Oxford University. The method was checked with the longer mathematical calculations for saturation deficiency determinations as described by Bates and Zon (2) and the necessary values supplied by Marvin (9). The observational method was found to be accurate to within the second decimal place.

Evaporation

This factor was not recorded during 1927. In subsequent years it was obtained by the use of Livingston standardized spherical atmometers. These were utilized in a Graham type set-up as described by Chapman (4). Usually, three atmometers were used at one time. These were exposed for five minutes and the average evaporation for the three instruments was used as the evaporation rate for the observation. The readings were corrected by the utilization of the coefficient stamped on each atmometer sphere. The utilization of three atmometers at one time eliminated the risk of losing records, as it was found that atmometers need constant care and attention if they are to be used successfully, and frequently one instrument would be out of order just at the time it was required. Evaporation is recorded in cubic centimetres of water evaporated per five minutes.

Rainfall

This was unrecorded in the plots during the first year and for this season the rain records of the Chatham Station of the Meteorological Service of Canada are utilized. This Station is situated about one mile from the plots. For all other years, rain was recorded at the edge of the corn field by use of a standard rain gauge. Rain is recorded in inches.

Atmospheric Pressure

For the years 1927 to 1934, inclusive, the barometric pressure readings used are those of the Chatham Weather Station of the Meteorological Service of Canada. Pressure was read at 8:00 a.m. each day. The Station is situated about one mile from observation plots. In 1935, we were able to purchase a mercurial barometer of our own, and for the years 1935 and 1936 records were taken one hour before sunset and again after the flight period had ended for that night, thus giving the change in pressure per hour during the time the moths were in flight. All readings were corrected for temperature and are given in inches of mercury.

Wind

Wind was measured in the field by use of a Biram portable anemometer. The instrument was set on a platform four feet from the ground. Five readings of one minute each were used to give the average wind velocity

for the period. It was found later in the work more desirable to take one five-minute reading. Readings were corrected according to the directions of the manufacturers of the instrument. The instruments were also checked for accuracy from time to time by the Physical Laboratory, National Research Council, Ottawa.

Wind is recorded in feet per minute. To convert the speed into miles per hour, feet per minute are multiplied by .01136. Similarly, if miles per hour squared is multiplied by .005, one obtains pressure per square foot.

Moonlight

Data regarding the phases and ascension of the moon at Chatham, Ontario, were obtained from the Canadian Almanac. Field records were made in regard to whether or not the moon was "in" or "out" at the time of observations.

Cloudiness

The general condition of the sky in regard to amount of clouds present at time of flight observations was recorded.

Light

The market was surveyed to obtain an instrument for the measurement of light intensity at night, but none could be found, until finally, in 1931 the ecophotometer as designed by Dr. A. B. Klugh (7) of Queen's University, was purchased and tried. This instrument was designed for daylight use and after a thorough trial it was found unsuitable for night work. The percentage transmission filter with which the instrument was fitted was too dense for light intensity at night and very little registration was obtained upon the panchromatic plates.

Dew

In the earlier years, the presence or absence of dew was observed irregularly. It was noted, however, that during the early years of work the dew was usually heavy. Later, regular observations were made and are complete for a number of years.

In 1936, a dew measuring instrument made by Wilh. Lambrecht, Germany, was loaned by the Meteorological Service of Canada for trial. Unfortunately, there was very little dew during the flight season and an adequate trial of the machine was impossible.

Guttation

As will be discussed later, guttation is a frequent phenomenon in the corn plant. A record of its presence or absence and abundance has been recorded for a number of the years.

(To be continued.)

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MALLING STOCKS AND FRENCH CRAB SEEDLINGS AS STOCKS FOR FIVE VARIETIES OF APPLES. II[1]

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[Received for publication, January 3, 1938]

At the end of the fifth year in the orchard a first report (5) on the Malling apple stock trial at the Ontario Horticultural Experiment Station was issued. The stocks under test and their classifications are as follows: French Crab seedlings and Malling XVI, very vigorous; Malling I, vigorous; and Malling II, semi-dwarfing. The present report, at the end of the eighth year, completes the records up to the end of 1937. As the building of a new highway has resulted in the loss (November 1937) of a few trees at one end of this orchard a summary of the results including these trees seems advisable at this time.

GROWTH

In a general way there has been little change since 1934 in the relative sizes of tree on the various stocks. In three varieties French Crab trees are the largest while Malling XVI trees are the largest in the other two varieties. Malling I trees are significantly the smallest except in Spy where the differences between Malling I and Malling XVI are not significant. Malling II trees show a tendency towards dwarfness in R. I. Greening, Melba, and Delicious, but this tendency is not so evident in the other two varieties. The trend of growth on all of these stocks is illustrated in Figures 1, 3, 5, 7 and 9.

The trees in this orchard have been given a light pruning each year, and to reduce variation in pruning treatment all the work has been done by the writer. The figures given in Table 1 show that there is, in a general

TABLE 1.— WEIGHT OF PRUNINGS, MEAN OF 16 TREES, 1931-37 INCLUSIVE (KGMS.)

——	French Crab	XVI	I	II
R. I. Greening	2 50	5 20	2.04	3.13
Melba	1 90	1 62	0 91	1 26
Delicious	1 77	1 36	0 99	1.15
Spy	0 69	0.53	0 40	0 45
McIntosh	2 29	1.48	1.24	1.42

way, a positive correlation between size of tree of a certain variety and the weight of prunings taken from those trees. However, heavy fruit production in weighting down the branches plays a part by its demand for the removal of those branches which hinder cultural operations.

[1] Presented at the meeting of the American Society for Horticultural Science, December 28-30, 1937.
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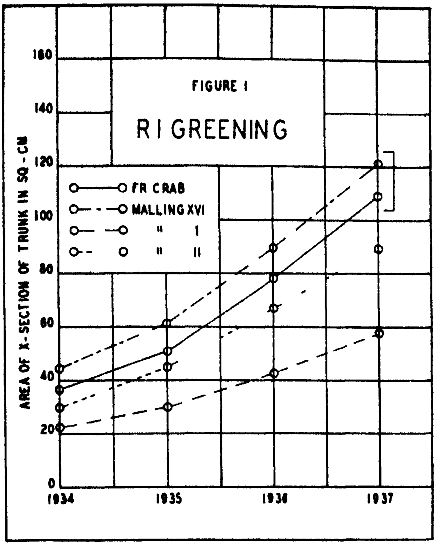
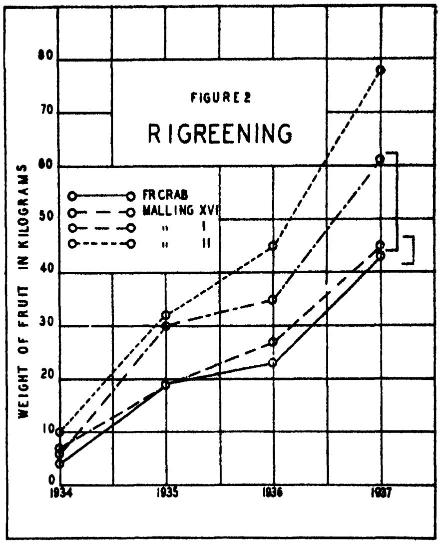
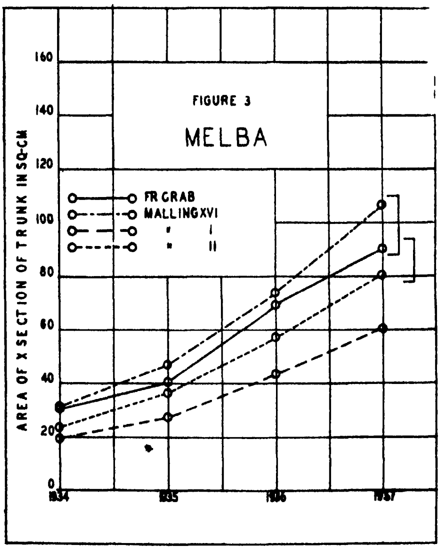
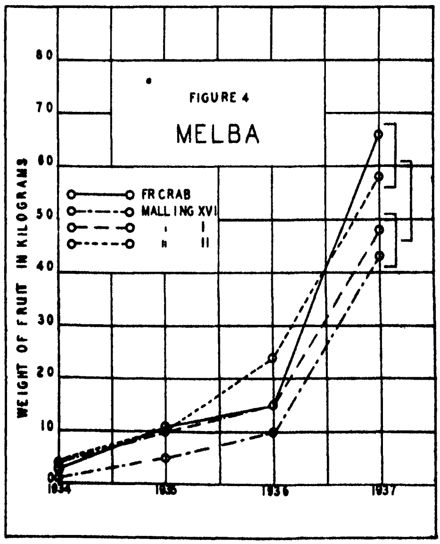








FIGURES 1 and 3. Comparative tree size of R. I. Greening and Melba on four stocks. Yearly area of cross section of trunk, means of 16 trees of each variety on each stock, have been plotted. 1937 measurements within brackets are not significantly different.

FIGURES 2 and 4. Accumulated yield of fruit, means of 16 trees. Yields bracketed together were not significantly different in 1937.

YIELD OF FRUIT

There has been enough fruit of all varieties, except Spy, to give some indications of precocity and early yields. The accumulated yields are given in Figures 2, 4, 6, 8 and 10. Malling II trees lead in yield per tree except in Melba, where French Crab trees have been slightly but not significantly more productive. Except in R. I. Greening, Malling XVI

trees seem to be even later in coming into bearing than French Crab seedling trees and in yield are still behind the trees on the other stocks.

In order to show the productiveness of trees on the various stocks for a constant area of trunk cross section, the only available measure of tree size in this trial, Table 2 has been compiled. Malling I and II share the honours, each being in the lead in two varieties. The only combination approaching Malling I and II trees is Melba on French Crab seedlings. Spy has not been included in this table because the yield has been too small to have any significance.

TABLE 2.—YIELD OF FRUIT (KGMS.), 1930-37 INCLUSIVE, PER 100 SQ. CMS. OF TRUNK CROSS-SECTION

——	French Crab	XVI	I	II
R. I Greening	39	50	78	**87**
Melba	72	40	**80***	72
Delicious	10	4	34	**36**
McIntosh	57	42	**90**	75

* The high reading for each variety is given in bold face type.

GRADE OF FRUIT

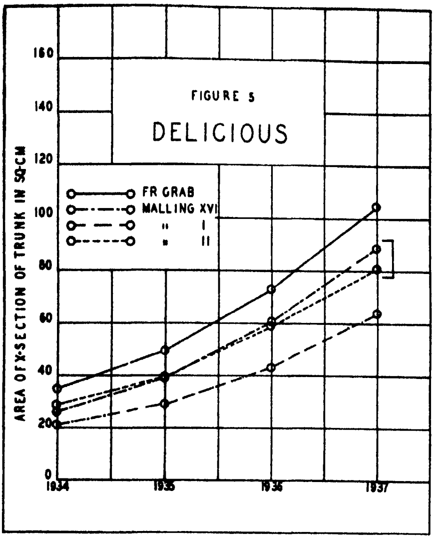
In 1936 and 1937 there was sufficient fruit of all varieties, except Spy, to make commercial grading worth while. First they were graded by hand into No. 1 and Domestic grades and then the machine separated the apples into the following diameter classes: below 5.7 cms.; 5.7 to 6.3 cms.; 6.4 to 7.0 cms.; 7.1 cms. and up. There was a very small percentage of the apples below 5.7 cms. in diameter.

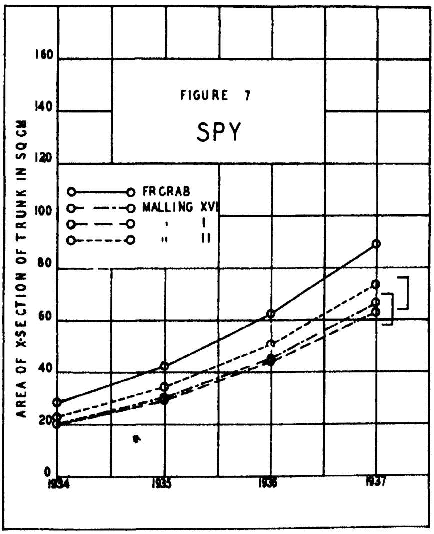
All of the trees on the Malling stocks of a given variety were propagated from buds of one strain, but in three varieties this strain could not be obtained on French Crab seedling roots and as a result the Delicious, McIntosh, and Spy trees on this stock are a different colour strain to the Malling trees and therefore not comparable to them in grade of fruit. Colour of fruit is a major factor in grade classifications so much so that, within a colour strain, grade can be used as an index to fruit colour. With this in mind the percentages of No. 1 fruit, averages of 1936 and 1937, from the stock-scion combinations are given in Table 3.

TABLE 3.—NO. 1 APPLES AS PERCENTAGES OF THE TOTAL CROP, AVERAGES OF 1936 AND 1937

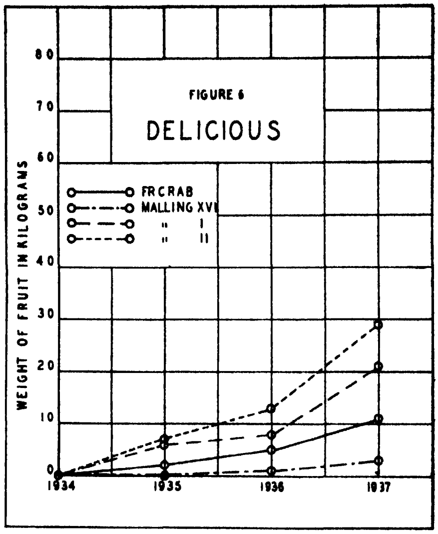
——	French Crab	XVI	I	II
R. I. Greening	48	53	**60***	56
Melba†	37	36	33	**39**
Delicious	73‡	70	**84**	76
McIntosh	58‡	**70**	44	50

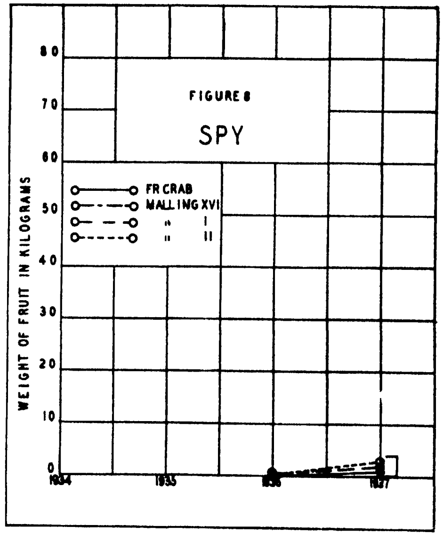
* The highest percentage for each variety is given in bold face type.
† 1937 only; hail injury in 1936 resulted in reduction of No. 1 fruit to negligible proportions.
‡ Different colour strain to the other trees and therefore not comparable to them.





FIGURES 5 and 7. Comparative tree size of Delicious and Spy on four stocks. Yearly area of cross section of trunk, means of 16 trees of each variety on each stock, have been plotted. 1937 measurements within brackets are not significantly different.





FIGURES 6 and 8. Accumulated yield of fruit, means of 16 trees. Yields bracketed together were not significantly different in 1937.

Too much significance must not be attached to the figures in Table 3 since they represent the records of only two years and of a period when the trees are still quite young. In spite of heavier crops for a given tree size (Table 2) Malling I and II trees have produced very high grade fruit. McIntosh apples from Malling XVI trees were decidedly better in colour

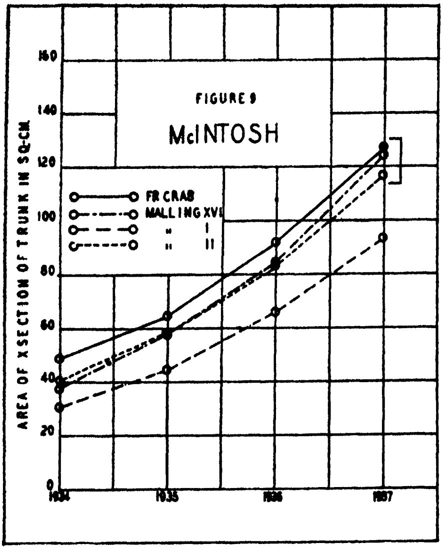


FIGURE 9. Comparative tree size of McIntosh on four stocks. Yearly area of cross section of trunk, means of 16 trees on each stock, have been plotted. 1937 measurements within brackets are not significantly different.

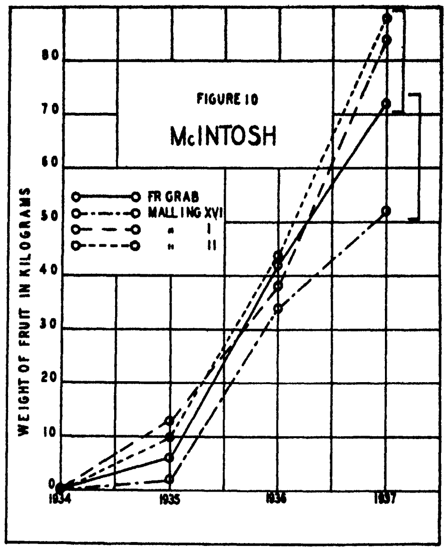


FIGURE 10. Accumulated yield of fruit, means of 16 trees. Yields bracketed together were not significantly different in 1937.

in 1936 than those from the other combinations but in 1937 the difference, though still in favour of Malling XVI, was comparatively small.

From the size grading figures the average diameters of apples from the stock-scion combinations can be computed with a reasonable degree of accuracy, and the results are given in Table 4. It is quite obvious that during these two years the differences in size of fruit were insignificant. Melba was lightly thinned in 1937 but this was the only thinning done in either year.

TABLE 4.—MEAN DIAMETER (CMS.) OF APPLES COMPUTED FROM SIZE GRADING FIGURES OF 1936 AND 1937

——	French Crab	XVI	I	II
R. I Greening	7.2	7.2	7.2	7.2
Melba	7.1	7.1	6.9	6.9
Delicious	7.1	7.1	7.0	7.0
McIntosh	7.1	7.1	7.1	7.1

EVIDENCES OF POTASSIUM DEFICIENCY IN THE TOP AS AFFECTED BY STOCK

In this orchard there is no doubt about the presence of a potassium starvation condition. Soil tests made in the fall of 1936 show that the readily available potassium is low in the surface soil and very low in the subsoil. From the spring of 1934 to the fall of 1936 eleven hundred pounds per acre of sulphate and muriate of potash have been applied on the surface

and immediately disked in, and in addition there was an application of barnyard manure at the rate of 15 tons per acre in the fall of 1935. From 1934 to 1937 buckwheat and rye have been the green manure crops. Leaf scorch, generally recognized as an evidence of potassium deficiency, has been evident to a certain extent on all varieties, but R. I. Greening has shown by far the most pronounced symptoms. On this variety records of amount of leaf scorch have been taken in 1935, 1936 and 1937 (Table 5).

TABLE 5.—ESTIMATED PERCENTAGE OF R. I. GREENING LEAVES SHOWING LEAF SCORCH, MEANS OF 16 TREES ON EACH STOCK

——	French Crab	XVI	I	II
1935	42	32	71	35
1936	28	8	48	20
1937	48	41	70	48

It appears that Malling I trees are suffering from potassium starvation to a much greater extent than are the trees on the other stocks. It is quite conceivable therefore, that this condition may explain why Malling I trees are so much smaller than the other trees (See Figures 1, 3, 5, 7 and 9). On a soil well supplied with readily available potassium the comparative tree sizes might be quite different. Malling XVI trees seem to be suffering least of all from potassium starvation, and in R. I. Greening they are outstanding in vigour of growth. In spite of heavy applications of potassium fertilizers in the past three years there has not yet been any lasting improvement in the condition of the foliage. In 1936 there seemed to be considerably less leaf scorch but in 1937 there was even more than in 1935. It is quite likely that the fluctuations are due to seasonal factors and that the added potassium has not yet become accessible to the roots.

VARIABILITY

Since 1934 there has been still further reduction in the coefficient of variability of the cross sectional area of the trunk of the trees on these stocks (Table 6). With the exception of Malling I trees all coefficients are now about 20 which represents a fair degree of uniformity in growth. French Crab seedling trees are no more variable than are the trees on the clonal stocks. During the past three years the size variability of Malling I trees has not been reduced to the same extent as it has with the other stocks. A possible explanation is the variable supply of potassium in the soil as it is quite evident that some of the R. I. Greening trees on Malling I are suffering from potassium starvation to a much greater extent than are other trees of the same combination.

The variability in yields (Table 6) is very much greater than the variability in trunk measurements. As variation in time of coming into full bearing and the biennial bearing habit enter into the yield figures it was probably inevitable that the yield variability would be high but it is surprising to see such a spread between the two sets of figures.

Scion rooting has not been any considerable factor in adding to the variability of the trees in this orchard. In the fall of 1937 all of the trees

TABLE 6.—COEFFICIENTS OF VARIABILITY

—		French Crab	XVI	I	II
Area of x-section of trunk (mean of 5 varieties)	1934	26	25	32	31
	1937	19	18	29	21
Yield, 1930-37 (mean of 4 varieties, Spy not included)		59	54	49	46

were examined for scion rooting. Only about 5% of them had scion roots and these mostly small in size; another 5% had roots so close to the region of the union that it was impossible to determine whether or not they were scion roots. All of the scion roots and most of the doubtful ones were cut off at this time. Trees on Malling I stocks had scion rooted to a greater extent than any of the others. Unless scion rooting is desired it appears to be advisable to plant fruit trees no deeper than they were in the nursery row.

MALLING IX

As the number of trees on Malling IX stock is very limited and as they are not interplanted with the trees on the other stocks but situated at one side of the orchard no direct comparisons have been made. Yet the data even though limited, seem to be worth presentation. One of the Spy trees was found to have a very large scion root and had to be eliminated from the records, reducing the number from nine to eight trees. This same scion-rooted tree has produced only 4 kilograms of fruit while the non-scion-rooted Spy trees have averaged 63 kilograms per tree. A few trees of the other varieties were found to have small scion roots which were removed in the fall of 1937. It is quite apparent that scion rooting may be a serious problem in the case of trees on Malling IX stocks as the scion roots may soon predominate over the original root system, resulting in the loss of the dwarf habit and early fruiting.

All varieties except Spy have been very considerably dwarfed by the Malling IX roots (Table 7) and, in view of heavy fruit bearing, it is surprising that Spy has continued to grow so vigorously. In yield per tree Malling IX trees are falling behind the larger trees on the other stocks in the early bearing varieties, R. I. Greening, Melba and McIntosh. In the less precocious varieties, Delicious and Spy, the Malling IX trees are still well in the lead. Fruits from Malling IX trees have been very well coloured, at least part of which seems to be due to earlier maturity. Considering the heavy crops borne the size of the apples has been quite satisfactory.

TABLE 7.—GROWTH AND YIELD OF TREES ON MALLING IX

—	Number of trees	Mean area of x-section of trunk, 1937 (sq. cms.)	Accumulated yield per tree up to 1937 (kgms.)
R. I Greening	3	38 5	56
Melba	6	22 2	40
Delicious	3	35 4	50
Spy	8	58.5	63
McIntosh	4	37.8	59

DISCUSSION

A careful examination of the growth and yield records in these apple stock trials shows that varieties differ in their response to stock effect. A stock that may be desirable for one variety for a certain purpose may not be the best one for another variety. The results at the East Malling (Eng.) Station as summarized in a recent paper by Hatton (1) demonstrate very well the varying effects of a certain stock on the scion varieties. To space trees of a certain combination in the orchard to the best advantage a grower ought to know the ultimate size of the tree, and it takes a long time to determine this.

Up to the present Malling II has proven to be a very satisfactory stock for McIntosh, and superior to Malling I, both with respect to growth and fruit production. In Massachusetts (3), on the other hand, three McIntosh trees on Malling II have been much inferior to McIntosh on Malling I stock. The latter stock also appears to be a very promising one for British Columbia conditions (2), but where there is low potassium availability, as in many Ontario orchards, it seems to be unwise to recommend it.

At least in the early years there seems to be but slight indication that the variability of apple trees can be reduced materially by the use of clonal stocks. The recent investigations of Shaw (3) and Spinks (4) point to the same conclusion. It appears that soil condition, physical and chemical, is a much more potent factor in creating variability than is stock.

SUMMARY

The Malling apple stock test orchard at the Ontario Horticultural Experiment Station has now completed its eighth year of growth. The stocks under test and their classifications are as follows: French Crab seedlings and Malling XVI, very vigorous; Malling I, vigorous; and Malling II, semi-dwarfing. Under the conditions of this trial the following conclusions may be drawn:

1. In three varieties French Crab seedling trees are larger than Malling XVI trees while the reverse is true with the other two varieties. Malling I trees are smaller than Malling II trees and there is no indication that the difference is becoming less.

2. Except in Melba, Malling II trees lead in fruit production on the per tree basis, and except in R. I. Greening, Malling XVI trees are the lowest in yield. On the basis of yield per 100 sq. cms. of trunk cross section Malling I and II trees have yielded considerably more fruit than French Crab and Malling XVI trees.

3. The larger crops on Malling I and II trees did not seem to react unfavourably on the colour of the fruit. There is a suggestion that Malling XVI trees may produce McIntosh apples of superior colour. In size of fruit there was no significant difference between the stocks.

4. Malling I trees appear to suffer most from potassium starvation and this may explain their slow growth as compared to Malling II trees.

5. There seems to be no reduction of variability in tree size by the use of clonal stocks in preference to seedling stocks but in fruit production the trees on clonal stocks have been slightly less variable.

6. Malling IX trees, not included in the above analysis, have been outstanding in precocity and heavy fruit production. The fruit matured earlier and was higher in colour than the fruit produced on any of the other stocks and the size of fruit was quite satisfactory.

ACKNOWLEDGMENT

The writer wishes to thank Mr. H. M. Gandier for making the graphs used in this paper.

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PRELIMINARY TESTS WITH PLANT HORMONES IN THE ROOTING OF GREENWOOD CUTTINGS[1]

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[Received for publication January 14, 1938]

As early as 1882 Sachs (1) pointed out that certain responses in plants were probably caused by some "specific substances". By 1919 it was known that decapitated oat plant tips contained some substance which stimulated growth reaction in plants (2). In 1925, Van der Lek (3) claimed to have proved that the influence of buds on the rooting of cuttings might be due to plant hormones formed in them, and transferred to the basal end of the cuttings where they promoted root reaction. In 1928, Went (4) demonstrated that growth promoting substances could be isolated from decapitated oat tips.

Since that time much literature has been published concerning plant hormones, their movement within the plant, and reaction on various plant parts. Dr. Zimmerman and Hitchcock, since their first tests in 1933 (5), have discovered that many synthetic substances have the capacity to stimulate root growth when applied to various plant parts (6).

This research has been applied practically by many experimenters during the past two years in using these synthetic growth substances as aids in the propagation of plants by cuttings. Commercial preparations have been placed on the market with recommended treatments for various species. The horticultural press has been full of advertisements and statements concerning the use of these chemicals, some of which have been misleading because they have not been backed up by sufficient experimental work.

During the winters of 1935–36 and 1936–37, Ferguson carried on tests at the Horticultural Division of the Central Experimental Farm to determine the reactions of hardwood cuttings of apple to treatment with some of these growth substances.

Cuttings were treated with indolebutyric, indoleacetic, and indoleproprionic acid both in water solution and lanolin paste but no positive reaction was obtained in either case.

The work described in this paper was carried on during the summer of 1937 to test the effectiveness of the better known commercial preparations in competition with solutions of indolebutyric acid prepared locally, and to determine if possible the optimum treatment to induce rooting of the various species and varieties tested, under conditions which obtain in the Canadian nursery trade.

EXPERIMENTAL

Materials

The following substances were tested in the strength indicated:

(a) Hortomone "A", a preparation of the Imperial Chemical Industries Limited, which contains naphthalene acetic acid as its active reagent.

[1] Contribution No. 500 from the Division of Horticulture, Dominion Experimental Farms System.

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1 part to 480 tap water.
1 part to 320 tap water, which is the strength recommended by the manufacturer.
1 part to 160 tap water.

(b) Hormodin "A", a product of Merck & Co., which contains indolebutyric acid.

10 BTI units which is 1 part to 400 tap water.
20 BTI units which is 1 part to 200 tap water.
40 BTI units which is 1 part to 100 tap water.
80 BTI units which is 1 part to 50 tap water.

(c) Auxilin, a product of the Pennsylvania Chemical Co., which also depends on indolebutyric acid, was tried at the five strengths recommended by the manufacturer.

1 part to 800 of tap water.
1 part to 400 of tap water.
1 part to 200 of tap water.
1 part to 100 of tap water.
1 part to 50 of tap water.

(d) Indolebutyric acid, prepared locally, was used in the first test at the following strengths:

5 p.p.m. of tap water	80 p.p.m. of tap water
10 p.p.m. of tap water	120 p.p.m. of tap water
20 p.p.m. of tap water	160 p.p.m. of tap water
40 p.p.m. of tap water	200 p.p.m. of tap water

In subsequent tests this was reduced to:

10 p.p.m. of tap water	80 p.p.m. of tap water
20 p.p.m. of tap water	100 p.p.m. of tap water
40 p.p.m. of tap water	

A 1% stock solution of the crystals was made in alcohol, and from this fresh water solutions were prepared each day to the required strengths.

The species and varieties varied somewhat in the different tests:

Sand,	Sand and peat,
Syringa vulgaris Peggy	*Syringa vulgaris* Norah
Syringa vulgaris Patricia	*Syringa vulgaris* Grace
Syringa Prestoniae Calphurnia	*Syringa vulgaris* Muriel
Syringa Prestoniae Jessica	*Syringa vulgaris* Maureen
Malus Antonovka	*Syringa Prestoniae* Celia
Malus Athabaska	*Syringa Prestoniae* Virgilia
Hydrangea paniculata	*Malus* Erie
Forsythia intermedia	*Malus* Hibernal
	Rose Agnes
	Rose Ellen Poulsen

Method

Chemical Treatment

Cuttings were taken at three different periods, mid June, late July, and early August. All were of the type most approved for the species by

the nursery trade; *i.e.*, some with a heel of last year's wood, some without, and from 2 to 4 inches long. Cuttings were tied in bundles of five, which was the unit of treatment, and stood with their basal ends in the various solutions to a depth of ½ inch to ¾ inch. The time of treatment varied from 6 to 48 hours, but the majority of cuttings were treated for 24 hours, as this period fits best into a daily routine of work.

Cultural Treatment

All cuttings were planted out of doors in cold frames with cotton shades on sides, and four feet above the top of the frame. Cuttings were syringed with water at least twice a day to keep up humidity and were left in the frame for a sufficient length of time to root the best treatments sufficiently for potting. This period of course varied with the different species.

In the first and third tests, some cuttings were planted in straight sand, and some in 50–50 sand and peat mixture. As lilacs predominated, all cuttings in these tests were kept closely covered with glass sash for the first four weeks, receiving only a little ventilation at noon.

In the second test, all cuttings were planted in sand and peat mixture, and some species which require more free circulation of air such as *Hydrangea paniculata*, were not covered with sash.

During the first test, records were taken at 9 a.m. each morning, the averages being as follows:

Soil temperature	70.3
Air temperature	72.1
Humidity	84.4

RESULTS

The following tables show the percentage of cuttings which rooted under each treatment, together with the length of time cuttings were left in the frame. Only those treatments which proved reasonably effective are indicated. In many cases cuttings had callused at the time results were checked and some of these rooted later. These are not shown, as the object of the work was to determine the optimum treatment for producing rooted plants.

DISCUSSION

Effectiveness of Treatment

While the Tables 1 and 2 show what seem to be rather low percentages in a number of instances, it must be kept in mind that under normal conditions our average for the species and varieties tested is much lower, and the length of time required for rooting much longer. Thorpe of the Horticultural Division, C.E.F., in 1935–36 rooted only 30% with *Syringa Calphurnia*, and 12% with *Syringa vulgaris* varieties when the cuttings remained in the frame for three months. According to the tables, *Syringa Calphurnia* rooted 80% at 80 ppm. of indolebutyric acid in 45 days, and *Syringa vulgaris* varieties rooted 40% at the same strength, which seems to be the best for lilacs throughout the tests. In 1936, the writer succeeded in rooting 60% of *Taxus cuspidata* cuttings after six months in the frame, whereas with 80 ppm. indolebutyric acid the same result took only 46 days.

All commercial preparations produced positive results at the strengths recommended by the manufacturers, though too much variation occurred to be able to recommend one treatment only for each species.

TABLE 1.

Plant name	No. of days	Check	Hortomone A 1–480	Hortomone A 1–320	Hortomone A 1–160	Hormodin A 10 unit	Hormodin A 20 unit	Hormodin A 40 unit	Hormodin A 80 unit	Indolebutyric acid 10 ppm.	Indolebutyric acid 20 ppm.	Indolebutyric acid 40 ppm.	Indolebutyric acid 80 ppm.	Indolebutyric acid 120 ppm.
TEST I														
Sand,														
Syringa vulg. Peggy	45	0	*	40	20	–	20	40	20	–	*	20	40	–
Syringa vulg. Patricia	45	0	*	20	*	–	*	20	*	–	–	*	20	–
Syringa Prestoniae Calphurnia	43	20	20	60	40	*	20	60	20	20	*	60	80	20
Syringa Prestoniae Jessica	43	0	*	20	*	–	*	20	–	–	*	20	20	–
Malus Antonovka	41	All malus cuttings dead.												
Malus Athabasca	41													
Hydrangea paniculata	35	20	80	60	–	80	60	–	–	40	80	40	–	–
Forsythia intermedia	33	0	20	20	–	–	20	–	–	–	–	20	–	–
Peat and Sand,														
Syringa vulg. Norah	45	0	0	20	*	–	*	20	*	–	–	*	20	20
Suringa vulg. Grace	44	0	0	40	*	0	*	20	*	–	*	*	20	20
Syringa vulg. Muriel	45	0	*	20	20	–	*	20	*	–	–	*	20	40
Syringa vulg. Maureen	44	0	*	40	20	–	–	20	*	–	–	*	40	20
Vulgaris Prest. Celia	43	0	*	40	20	0	*	40	20	0	–	*	40	20
Syringa Prest. Vigilia	43	0	*	20	*	*	*	20	–	*	*	20	–	–
Malus Erie	39	All malus cuttings dead.												
Malus Hibernal	39													

* Cuttings in more advanced condition than check unit though none rooted.

– Cuttings dead or damaged.

TABLE 2

Plant name	No of days	Check	Hortomone A			Hormodin A				Indolebutyric acid					Auxilin				
			1–480	1–320	1 160	10 unit	20 unit	40 unit	80 unit	10 ppm	20 ppm	40 ppm	80 ppm	100 ppm	1	2	3	4	5
TEST II																			
Sand and peat																			
Hydrangea paniculata	30	40	60	40	–	100	40	–	–	20	100	40	–	–	20	–	20	40	80
Rose Sylvia	36	0	40	–	–	40	20	–	–	*	20	–	–	–	60	20	–	–	–
Rose Ellen Poulsen	36	0	20	20	–	40	20	–	–	*	20	40	–	–	20	20	20	–	–
Syringa Prest Virgilia	45	0	–	20	20	*	*	40	20	–	*	20	40	20	*	*	–	20	40
Syringa vulg Thumberg	45	0	*	20	*	–	*	60	20	–	*	*	40	20	*	*	*	*	40
Forsythia intermedia	45	0	*	40	20	*	–	60	20	–	20	60	20	–	–	–	20	100	20
Viburnam Lantana	45	0	0	20	0	–	*	20	–	–	–	20	*	–	–	–	–	–	–
Malus floribunda	45	0	0	20	All others dead														
Thuja occ Wareana	52	0	0	20	60	0	20	100	40	0	–	*	20	80	0	–	*	20	50
Thuja occ pyramidalis	53	0	0	*	40	0	*	20	60	–	–	0	40	80	0	*	40	20	20
Juniperus sabina	52	0	0	*	40	0	*	20	40	0	0	*	20	60	0	0	*	60	*
Taxus cuspidata	53	0	0	20	40	0	20	60	20	0	–	40	60	20	0	0	0	*	*
TEST III																			
Sand																			
Syringa Prest Miranda	46	20	20	60	20	*	60	20	–	60	40	–	–	–	*	*	60	20	–
Syringa vulg Thumberg	46	20	40	20	–	20	*	*	*	20	*	*	*	*	40	20	*	*	*
Thuja occidentalis	43	0	0	20	0	0	20	*	0	0	0	20	20	0	0	*	20	*	0
Malus Patton Greening	46	*	*	*	–	*	*	–	–	*	*	–	–	–	*	*	–	–	–
Peat and sand																			
Syringa Prest Miranda	46	20	*	60	*	*	40	40	–	*	20	60	20	–	*	–	20	40	20
Syringa vulg Thumberg	46	20	20	40	20	*	40	*	*	20	60	20	–	–	20	40	*	–	–
Thuja occidentalis	43	0	*	40	*	0	20	0	0	0	*	40	40	0	0	40	0	0	–
Malus Patton Greening	46	*	0	*	*	*	*	0	–	*	*	*	–	–	*	*	*	0	–

* Cuttings in more advanced condition than check unit though none rooted

- Cuttings dead or damaged

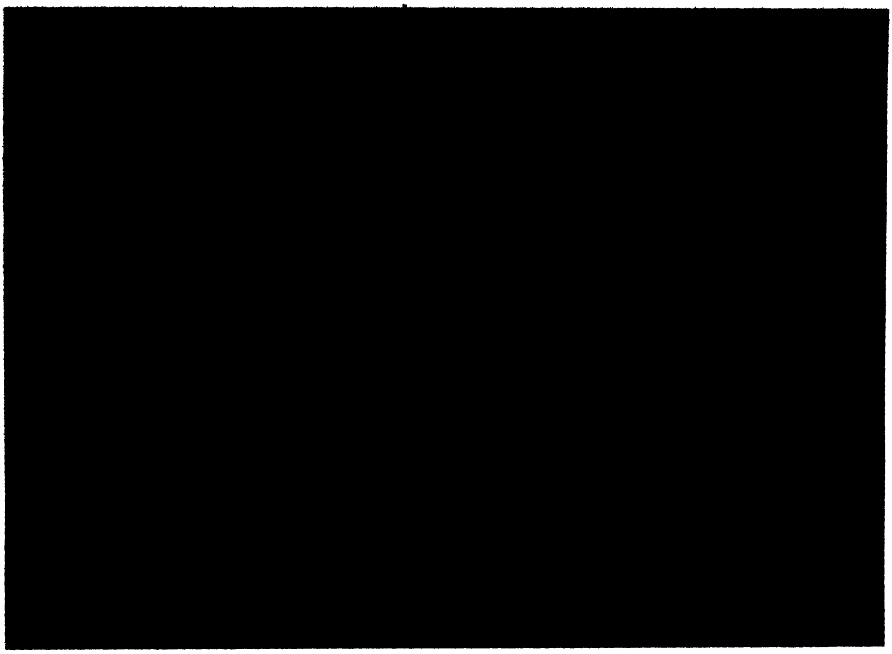

FIGURE 1. *Syringa Culphurnia* Left to right check, 10 ppm. 20%; 40 ppm. 60%; 80 ppm. 80%; 120 ppm. 20%; 160 ppm. 40%; bases rotted off.

FIGURE 2. *Hydrangea paniculata.* Top untreated, bottom 10 BTI units Hormodin.

In general, the roots produced by Hortomone A (naphthalene acetic acid) were stockier than the others, though results were not quite so high as a rule.

From the tables we can readily see the comparative strengths of the products containing indolebutyric acid when they are compared with the results obtained by treatment with the straight chemical. (It is quite evident from the consistency of the results that one BTI unit (Boyce Thompson Institute) is equal to 2 ppm.)

Root Development

There seems to be no direct progressive relationship between root development and concentration of chemical except within the narrow limits of the effective zone. In some cases where checks and cuttings treated with weak solutions remained healthy and rooting occurred at fairly high concentrations, there seemed to be an intermediate concentration which caused damage or death. Very strong concentrations 120 to 200 ppm. indolebutyric acid caused splitting and burning with consequent death in many cases Often cuttings damaged in this way rooted from higher up the stem even though the base of the cutting rotted off. This was particularly the case with *Hydrangea* and other softer wooded plants.

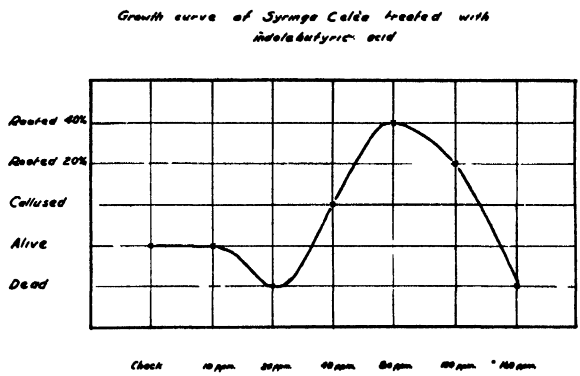

FIGURE 3. Growth curve of *Syringa celia* treated with indolebutyric acid

These points are more readily seen in Figure 3 which represents the results with *Syringa* Celia.

The quality of root was much stockier and of a lighter colour and the number of roots much higher than in normally rooted cuttings. This was particularly the case in the higher concentrations.

Absorption and Its Effect

Apparently the quantity of the solution absorbed, as well as the concentration, has a large influence on the rooting. In the first test *Syringa* Virgilia was treated in a window where it received sunlight during the morning hours and obviously received an overdose of the chemical, though *Syringa* Celia rooted quite well at the same concentrations.

During the second test, records were kept at the time of treatment, which showed that under normal light from a northeast window the average cutting of lilac or apple absorbed 2.4 cc. of solution in 24 hours, while

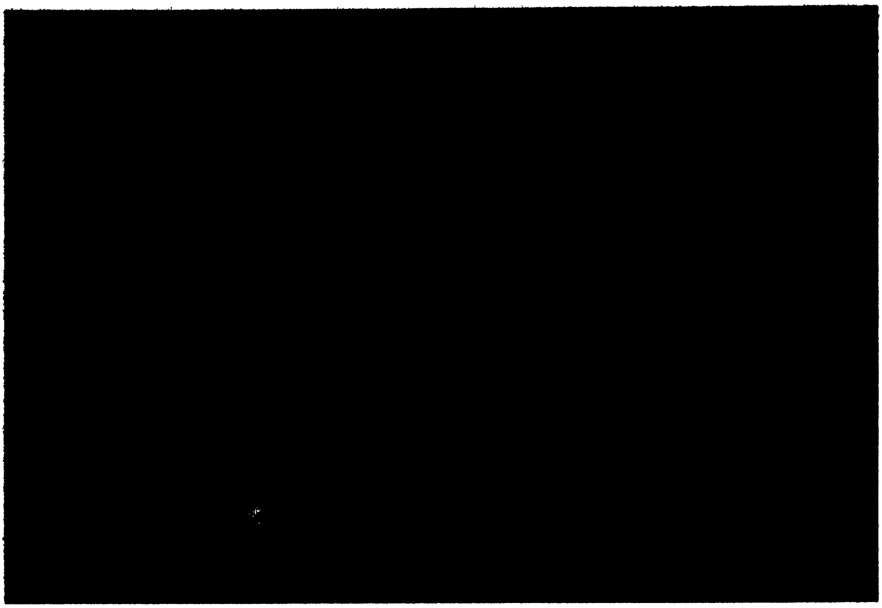

FIGURE 4 Lilac cuttings showing enlarged cuttings

cuttings exposed to sunshine during the morning hours and skylight for the remainder absorbed 4 9 cc. In coniferous cuttings the rate of absorption was 0 5 cc.

As the rate of absorption will also vary with the temperature and humidity of the room in which the cuttings are treated, all these factors of light, heat, and humidity will have a bearing on the optimum treatment.

Sand vs. Peat

Under normal conditions, lilacs root more readily in a sand-peat mixture. From the above result the reverse would seem to be the case when hormones are used. Also from the tables for Test III, it would appear that in the case of *Thuja*, which normally has a very strong preference for peat, lower concentrations are necessary where sand is the medium than where peat and sand is used. This would indicate that the pH content is also a factor influencing the optimum treatment.

In lilacs, the majority of cuttings which formed callus in sand rooted well, while in peat and sand mixture more cuttings callused but many failed to root and simply increased the amount of callus over a period of three months.

CONCLUSIONS

(1) The plant hormones tested are of value to the nursery trade in hastening the rooting of greenwood cuttings and increasing the percentage rooted.

(2) Species and varieties reacted positively to varying concentrations so that an optimum treatment must be found for each species.

(3) This optimum treatment will be influenced by the light, temperature, and humidity conditions under which the cuttings are treated; by

the degree of ripeness of the wood and by the pH of the medium in which they are planted.

(4) The optimum treatment for the species tested is approximately as follows in terms of indolebutyric acid:

Syringa vulgaris and *Prestoniae* varieties	80 ppm.
Hydrangea paniculata	20 ppm.
Forsythia intermedia	40 ppm.
Roses	20–40 ppm.
Taxus cuspidata	80 ppm.
Thuja occidentalis and varieties	100 ppm.
Juniperus sabina	80 ppm.

(5) Apples of the varieties tried do not respond readily.

From these conclusions it will be seen that a great deal of work must be done before definite treatments can be recommended with any degree of safety. For the present the grower should try two or three strengths ranging around those mentioned above.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation and gratitude to Dr. R. H. Manske and Dr. N. H. Grace of the National Research Council for their co-operation in supplying various growth substances as well as a great many helpful suggestions.

Thanks are also due to William Ferguson and Roland Thorpe, both of the Division of Horticulture, Central Experimental Farm, Ottawa for the references to their work.

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BORON DEFICIENCY IN CAULIFLOWER[1]

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[Received for publication February 2, 1938]

Many workers in different parts of the world have shown that the element boron has a very definite place in plant nutrition. A deficiency of this element has produced physiological diseases of grave economic importance in some of our cultivated plants. In recent years it has been found that applications of boron either as boric acid or borax will prevent such important disorders as brownheart of turnips, and cork and drought spot of apples.

Deficiencies of this element may cause disorders which have not been recognized from symptoms evidenced in other plants.

In so far as possible it is one of the purposes of this laboratory not only to find the causes of nutritional disorders and means of their prevention, but also to anticipate such disorders. An experiment in this connection has brought to light very interesting information on the effect of boron deficiency in cauliflower plants.

PROCEDURE

Cauliflower seed, variety Early Snowball, were germinated in greenhouse soil. When large enough they were pricked out into 4-inch pots containing ground, washed sandstone. The plants were held in these pots until the root system was large enough to permit transferring to 2-gallon glazed jars containing ground, washed sandstone.

The nutrient solution supplied to these plants was based on that used by Hill and Grant (2). The amount of boric acid stock solution (1 gm. H_3BO_3 in 1000 cc. water) added to the feeding solution varied with the treatment from 0 cc. to 23 cc. The feeding solution was applied at the rate of 200 cc. weekly per plant. This was increased to 300 cc. as the amount of growth increased.

Parts per million of the elements in the feeding solution were·

N	P	K	Mg	Ca	S	Cl	Fe	Mn
1553	123.7	929.4	96.4	400	127	352	33.04	0.29

The concentrations of boron in the feeding solution according to the treatment were, 0, 0.25, 0.5, 0.75, 1.0, 1.5 and 2.0 parts per million.

RESULTS

The plants under all the treatments continued to grow in a normal and healthy fashion until the curd began to show. From this time on the differences between the boron deficient plants and those receiving boron became increasingly more marked.

On the boron deficient plants the smaller leaves, surrounding the curd became deformed and twisted with the characteristic stunted appearance of boron-starved plants. This condition gradually became worse

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until the condition shown in Figure 1-B was reached. Some of these smaller leaves became so deformed and stunted that they consisted of little more than the main stalk. From the time the curd appeared it remained very small, almost in a vestigial state. Very little of the usual branching of the curd took place and no flowers developed. The top of the curd remained brown in colour from the time of its appearance.

The boron-fed plants all showed normal growth regardless of the concentration of boron in the feeding solution. Figure 1-A shows a normal plant on which the leaves and curd are healthy in every respect. This plant received a concentration of 0.25 p.p.m. of boron in the feeding solution.

Figure 1. A. Plant fed 0 25 p.p.m. boron in feeding solution. B. Plant fed 0 p.p.m. boron in feeding solution.

When these plants were cut through from top to bottom the browning on the surface of the boron deficient curd was found to extend down into the flesh and even into the stalk as seen in Figure 2-A. These internal areas presented much the same brownish, water-soaked appearance as the areas denoting brownheart in turnip roots. Figure 2-B illustrates the normal, healthy development secured when the plants receive 0.25 p.p.m. of boron in the feeding solution.

The effect boron has had in producing large, healthy white curds as contrasted with the small, brown curds produced by boron deficient plants is noteworthy. Thus, applications of boron to the soil may prevent the formation of brown coloured cauliflower curds which were so prevalent in Eastern Ontario in 1937.

A B

FIGURE 2. A. Section through plant receiving 0 p.p.m. boron. B. Section through plant receiving 0.25 p.p.m. boron.

CONCLUSIONS

Boron is essential for the normal, healthy growth of cauliflower.

Insufficient boron will cause a stunting and deformation of the leaves immediately surrounding the curd.

Insufficient boron will result in the production of smaller curds, incompletely developed and brown in colour.

Insufficient boron will result in the appearance of brownish, water-soaked areas in the flesh and stalk.

A concentration of 0.25 p.p.m. of boron in the feeding solution applied to plants growing in sandstone is sufficient to produce normal plants.

APPENDIX

Subsequent to arriving at the above conclusions, the paper by Dearborn, Thompson and Raleigh (1) reporting similar results was received.

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LES FERMENTS

APPLICATION DE LEUR SPÉCIFICITÉ À LA RECHERCHE DES OSIDES DANS LES PLANTES

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I.—NOTIONS GÉNÉRALES SUR LES FERMENTS

C'est au début du XIXième siècle, à la suite des recherches de Dubrunfaut et de Mitscherlich que furent découvertes des substances spéciales qui reçurent des dénominations différentes suivant les auteurs: Kühne leur donna le nom d'enzymes, alors qu'en France Payer et Persoz les dénommaient diastases; d'autres enfin recoururent au terme de ferments solubles par opposition au terme de ferments figurés, tout en faisant remarquer qu'à leur avis il n'y avait pas lieu d'établir cette distinction puisque les ferments solubles possédaient les mêmes propriétés que les ferments figurés, et que par conséquent une même désignation pouvait s'appliquer aux deux catégories.

Cette hypothèse fut reconnue sans fondement à la suite des recherches de Büchner sur la levure de bière. Cet auteur montra que la levure de bière (ferment figuré) ne provoquait le dédoublement du sucrose en glucose et lévulose que par la sécrétion d'une substance spéciale (ferment soluble) appelée invertine ou sucrase. En effet grâce à l'action de la presse hydraulique il réussit à extraire de cette levure un liquide qui mis en présence de saccharose provoquait aussi la transformation du sucre. Ce n'est donc pas la cellule elle-même qui provoque cette réaction fermentaire mais les produits qu'elle secrète; elle se comporte d'une façon identique aux cellules de l'estomac qui secrètent de la pepsine. Cette distinction entre les ferments est donc nécessaire.

Dans les années qui suivirent, on découvrit grand nombre de diastases tant dans le règne animal que dans le végétal. Si bien qu'on en tira la loi générale suivante: chez les animaux elles président aux phénomènes de dégradation des aliments et à leur assimilation (Cl. Bernard), et chez les végétaux elles déterminent les réactions de synthèse (Bourquelot) pour la mise en réserve des principes immédiats élaborés. C'est ce qui fit dire à Cl. Bernard que les ferments doivent contenir le secret de la vie, sans être toute la vie, car tandis que l'anesthésie supprime les sensations, le mouvement, elle reste sans action sur les processus fermentaires de métabolisme.

Ces manières de voir ne furent pas admises entièrement par nombre de biologistes, et Colin notamment s'exprime ainsi: on ne peut définir la vie comme une source de phénomènes diastasiques. Un petit nombre seulement de réactions intracellulaires relèvent d'enzymes authentiques; ce sont surtout des réactions de dégradation; elles s'effectuent tout aussi bien in vitro et ne dépendent de la vie qu'en raison des ferments qui les provoquent. Il en va tout autrement des opérations de synthèse; celles-ci sont inséparables de la vie et rien n'autorise à les assimiler purement et simplement à des phénomènes diastasiques.

Nature des Ferments

Deux théories s'opposent: l'une qui considère la diastase comme une substance chimique définie (diastase substance), l'autre qui ne considère la diastase que comme une source d'énergie (diastase propriété). Malgré toutes les recherches et les faits en faveur de l'une ou de l'autre, la question reste encore toute entière.

Les partisans de la première théorie considèrant la diastase comme un corps défini, voulurent employer pour sa purification et son isolement les méthodes chimiques habituelles. Ce n'est qu'en 1928 que Sumner réussit à isoler pour la première fois une diastase, l'uréase, sous une forme cristallisée. D'après cet auteur, il s'agirait d'une globuline dont l'activité s'accroit par cristallisation successive. Plus tard, en 1929 Northrop préparait de la même façon de la pepsine cristallisée.

Mais est-ce que ces découvertes permettent de généraliser? L'uréase et la pepsine faisant partie des protéases, pourra-t-on juger de la même façon les glucidases ou les lipases? Willstatter chercha à résoudre la question, mais toutes ses tentatives ont échoué car au fur et à mesure que la purification s'avancait les propriétés des diastases allaient en s'évanouissant pour disparaître complètement.

Il y a d'ailleurs là une analogie avec les colloïdes, et c'est pourquoi on a classé les ferments parmi les substances colloïdales. Considérons le trisulfure d'arsénic As^2S^3; ce corps à l'état colloïdal présente la formule de masse variable As^2S^3, nSH^2 où nSH^2 représente une impureté nécessaire pour que le corps prenne et garde l'état colloïdal. Si on cherche à le purifier, et par conséquent à ôter nSH^2, le corps perd son état particulier. C'est identique à ce qui se passe pour les diastases. Il suffit de se rapporter aux belles recherches de G. Bertrand sur la laccase contenue dans le latex de l'arbre à laque. Elle serait constituée par une substance organique sur laquelle serait fixées par adsorption des micelles de manganèse; cet ensemble constitue le système actif. Otons l'impureté constituée par le manganèse, et aussitôt les propriétés oxydantes disparaissent. Nous arrivons ainsi à la théorie de la diastase propriété d'après laquelle les substances minérales à l'état de très fines particules étant fixées à la surface de la molécule détermineraient dans le système un déséquilibre ionique. Cette action des micelles sur les électrolytes prévoit immédiatement la possibilité de l'utilisation d'une certaine quantité de l'énergie intramoléculaire, et l'on peut s'expliquer de cette façon la puissance des phénomènes diastasiques.

Si l'on compare l'action des diastases à celle des catalyseurs, on constate une grande analogie. Les métaux colloïdaux par exemple, présentent des conditions d'action qui ressemblent étrangement à celles des ferments: l'activité des métaux colloïdaux est détruite à 100°, ils agissent à des pH déterminés, ils peuvent être paralysés par certains toxiques comme l'acide cyanhydrique ou le sublimé.

On sait que des catalyseurs sont des corps qui modifient la vitesse d'une réaction sans être détruits. C'est aussi le cas des diastases. Un grand nombre de réactions fermentaires peuvent être accomplies à l'aide de catalyseurs minéraux: ainsi un protide peut être dégradé à l'état de peptones à 40° sous l'action de l'acide chlorhydrique fort, ou à 100° sous l'action de HCl étendu. Les protéases accomplissent ces mêmes réactions

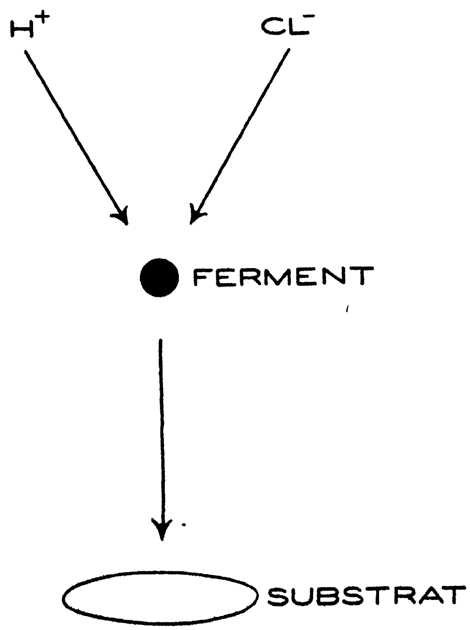
aussi rapidement à la température du corps et dans des conditions compatibles avec la vie des cellules. Cette action plus douce et aussi rapide que les méthodes chimiques montre la valeur des diastases comme agents du chimisme cellulaire. En se basant sur ces propriétés Bourquelot eut l'idée d'utiliser ces agents comme réactifs de laboratoire et ainsi imagina les méthodes biochimiques. Ses recherches l'amenèrent à étudier la réversibilité des réactions et à considérer les diastases comme des catalyseurs susceptibles de détruire ou de construire suivant les nécessités et les conditions de la vie: chez les plantes, elles joueraient un rôle antitoxique en éliminant les composés dangereux ou en excédant (Goris).

Cette théorie de Bourquelot sur les synthèses et les réactions réversibles reçut récemment une confirmation brillante lors de la découverte en 1925 par Wattiez du méthylglucoside β dans les dipsacées. Bourquelot étant arrivé à faire in vitro cet oside en utilisant les méthodes fermentaires, estima qu'on devait le rencontrer dans le monde végétal; c'est ce qui eut lieu 20 ans plus tard.

D'après ce que nous venons de voir la définition la plus exacte des diastases serait la suivante: des catalyseurs biochimiques solubles, colloïdaux, extraits des tissus vivants (Wattiez et Sternon).

Conditions d'action et mode d'action des ferments

Toute action fermentaire nécessite la présence d'eau, un certain pH du milieu, et la présence de deux substances appelées co-ferment et ferment. D'après Ambard, une substance dite co-ferment, par elle-même inactive confère à une autre substance dite ferment, par elle-même également inactive, la propriété de transformer une tierce substance. Pour analyser le mécanisme des actions diastasiques reportons-nous à un travail récent de cet auteur sur l'amylase.



Une réaction fermentaire hydrolysante peut se décomposer en 3 processus: la fixation du co-ferment sur le ferment, la fixation du complexe coferment-ferment sur le substrat et l'hydrolyse proprement dite du substrat.

D'après la reproduction ci-dessus, on comprend que l'hydrolyse est une résultante de deux facteurs qui peuvent varier indépendamment l'un de l'autre. Ambard a montré que pour l'amylase, il existe un co-ferment formé d'un ion H et d'un anion monovalent, et qu'en l'absence de co-ferment, l'amylase ne s'unit pas avec l'amidon et par conséquent l'hydrolyse ne peut avoir lieu. Ainsi une solution d'amylase active devient in-

active si on élimine complètement les electrolytes par dialyse, toutefois la réactivation peut être réalisée si on ajoute NaCl.

En résumé, il semble qu'à l'heure actuelle on doive considérer un système fermentaire comme formé de 3 constituants: des electrolytes, un support colloïdal et enfin le groupe actif ou diastase proprement dite.

Propriétés des ferments

Ils se dissolvent dans l'eau et la glycérine, tandis que l'alcool les précipite de leur solution. C'est sur ce principe que sont basées toutes les méthodes de préparation et d'extraction des ferments.

Si l'on considère après une action fermentaire, la quantité de diastase qui a agi et la quantité des produits de transformation, on est frappé par la disproportion entre l'effet et la cause. Ainsi la présure du suc gastrique est capable de coaguler de 400.000 à 800.000 fois son poids de caséine (Hammarsten).

Les diastases ne se détruisent pas en agissant, une masse donnée de diastase pouvant, à condition d'éliminer les produits formés, transformer une quantité à peu près illimitée de substance. Si nous mettons des ferments lactiques en présence de lait, aussitôt, si les conditions sont favorables, la vitesse de réaction atteindra une certaine valeur, passera par un maximum, puis diminuera pour atteindre à la fin une valeur nulle. Ce fait n'est pas dû à une destruction des ferments, mais est causé par un excès d'acidité dû à l'acide lactique; en effet si l'on neutralise cet acide ou si on l'isole, on constate que les réactions de transformation recommencent, s'il existe encore du lactose dans le milieu.

La température joue un rôle important dans les actions fermentaires. A 0° l'activité diastasique est suspendue et les basses températures ne les détruisent pas; à partir de 0° l'activité croit pour passer par un maximum pour une température optima comprise entre 40 et 55°. Vers 60 ou 70° en milieu liquide les diastases sont détruites, alors qu'en milieu sec elles peuvent résister jusqu'à 100°.

Les antiseptiques qui s'opposent à la multiplication cellulaire ont aussi une action quoiqu'à un degré moindre sur les ferments solubles. Ces derniers sont beaucoup plus résistants que les éléments cellulaires; il ne s'agit là que d'une question de proportion qui est utilisée lorsqu'on veut arrêter une multiplication cellulaire sans entraver une action fermentaire, et dans ce cas, il suffit de choisir une dose convenable d'antiseptique.

Spécificité des ferments

Nous avons préféré traiter cette question séparément, parce que c'est sur cette propriété que sont basées les méthodes biochimiques.

La spécificité des ferments a été mise en évidence depuis longtemps, mais de nos jours elle semble très discutée. Si l'on considère les grands groupes tels que les glucidases, les protéases, les lipases, on n'a aucune peine à admettre la spécificité de chacun d'eux, mais dès que l'on examine séparément les diastases d'un même groupe, la difficulté apparaît, et cette difficulté est d'autant plus grande que pour les classer on ne peut se baser sur leur composition qui nous est inconnue. Les méthodes employées pour étudier la spécificité sont au nombre de trois: 1°—La méthode comparative qui étudie parallèlement les diastases provenant de plusieurs

sources sur un même corps. La trypsine (protéase animale) et la papaïne (protéase végétale) possèdent la même action sur les protides, mais diffèrent l'une de l'autre, car la première n'agit qu'en milieu alcalin et la deuxième qu'en milieu acide. 2°—La méthode de destruction qui consiste à détruire par la chaleur ou les antiseptiques certaines diastases contenues dans un milieu fermentaire. De cette façon Bridel et Arnold détruise la sucrase qui se trouve toujours dans l'émulsine des amandes amères, en traitant le complexe fermentaire par l'alcool fort. 3°—La méthode basée sur les vitesses de réaction.

On connaît l'expression de Fischer qui assimilait l'action d'une diastase sur un corps à une clef s'adaptant sur une serrure. C'est d'ailleurs sur la spécificité que cet auteur s'est basé pour classer les osides soit dans la série α soit dans la série β, car il a vu que les osides α étaient dédoublables par la levure et les osides β par l'émulsine. Ainsi la spécificité absolue n'existe pas: Kühne avait déjà constaté que la β glucosiadase dédouble non seulement le β méthylglucoside, mais aussi le prunasoside, le salicoside, l'arbutoside, et Willstatter avait prouvé que la levure attaque aussi bien le maltose que l'α méthylglucoside et que l'α phénylglucoside.

Il n'existerait donc pas de spécificité absolue d'espèce mais une spécificité de groupes de fermentation comprenant des corps qui présentent des analogies du point de vue constitution stéréochimique.

A quoi serait dû la spécificité? Certains auteurs admettent que les diastases présentent des différences de structure analogues à celles qui existent pour les glucides des séries α et β (Fischer et Schoen). D'après Kopaczewski la spécificité serait due, sinon exclusivement, tout au moins en grande partie, à la présence d'ions fixés sur la micelle colloïdale.

Pour nous résumer sur cette question qu'il nous suffise de citer l'avis de G. Bertrand: Le réactif diastasique dont l'action paraissait d'une spécificité absolue quand on se bornait à l'étudier dans ses rapports avec le principe immédiat attaquable, à côté duquel on l'avait découvert, n'a plus qu'une action spécifique relative quand on vient à reconnaître la fonction ou la structure chimique qui rendait le principe immédiat tributaire de son action.

II.—APPLICATION DE LA SPÉCIFICITÉ. MÉTHODES BIOCHIMIQUES

C'est en se basant sur le fait que les diastases s'attaquent de préférence à certains composés, que Bourquelot eut l'idée dès 1906 de les utiliser dans la recherche des glucosides dans les plantes à la place des réactifs chimiques dont l'action trop brutale peut décomposer et altérer les corps mis en liberté. Pour montrer l'importance de la découverte de Bourquelot, il suffira de rappeler brièvement l'état de nos connaissances au début du XIXième siècle.

A cette époque un pharmacien Derosne avait réussi à extraire de l'opium, un alcaloïde: la morphine. Le procédé général d'extraction fut employé par nombre de savants dans le but de connaître les principes actifs des plantes en usage dans la pharmacopée. Mais qu'elle ne fut pas leur étonnement en s'aperçevant que nombre de plantes que l'on utilisait dans telle ou telle maladie ne renfermait aucun principe isolable par la méthode de Dérosne. On en conclut qu'elles n'avaient aucun pouvoir thérapeutique et on les délaissa jusqu'en 1829 où un autre pharmacien

réussit à isoler de l'écorce de saule un principe tout différent de ceux qu'on avait extrait jusqu'alors: la salicine. Contrairement aux alcaloïdes, la salicine était incapable de donner des sels avec les acides, et sous l'influence de l'acide sulfurique elle était décomposée en donnant naissance à un sucre réducteur que l'on pensait toujours être du glucose d'où le nom de glucosides qui fut attribué à ce nouveau groupe de corps. En 1901 on connaissait déjà 14 glucosides, sans que l'on ait trouvé aucune méthode générale pour les décéler et les identifier. En 1906 Bourquelot en se basant sur ses recherches sur l'émulsine et l'invertine, songea à les utiliser pour reconnaître la présence des holosides et des hétérosides; les méthodes biochimiques étaient découvertes. Le procédé peut se résumer dans la combinaison d'un examen au polarimètre et d'un dosage des substances réductrices. Les deux ferments qu'il utilisa furent l'invertine et l'émulsine. L'invertine de la levure paraissait ne s'attaquer qu'au saccharose libre ou combiné. L'émulsine n'agissait que sur les hétérosides lévogyres et le seul produit actif sur la lumière polarisée qu'elle mettait en liberté était le glucose, corps dextrogyre.

Voyons en détail l'action de ces deux ferments:

1° Méthode à l'invertine.

L'invertine ou sucrase agit sur tous les corps dextrogyres et non réducteurs, diholosides, triholosides, tetraholosides, en libérant une molécule de fructose aux dépens du saccharose libre ou combiné, et en déterminant un changement de rotation vers la gauche. En même temps le liquide devient réducteur.

Voici, d'après A. Meunier, des schémas qui feront comprendre l'action de la sucrase.

$$\text{Saccharose} + H^{2}O = \underbrace{\textit{fructose} + \text{glucose}}_{\text{saccharose}}$$

$$\text{Raffinose} + H^{2}O = \textit{fructose} + \underbrace{\text{glucose} + \text{galactose}}_{\text{mélibiose}}$$

$$\text{Stachyose} + H^{2}O = \textit{fructose} + \underbrace{\text{glucose} + \text{galactose} + \text{galactose}}_{\text{manninotriose}}$$

Par cette méthode Bourquelot a imaginé un indice caractéristique pour chaque oside, il l'a appelé Indice enzymolytique (q): c'est le nombre de milligrammes de produits réducteurs exprimés en glucose, formés dans 100cc de solution sous l'influence de l'invertine pour un changement de déviation de 1° observé au tube de 2 décimètres. Cet indice qui semblait spécifique au début, s'est montré en défaut en 1920 où l'on constata que l'invertine renfermait des ferments capables d'hydrolyser certains fructoholosides et même un glucoholoside, le laminaroholoside. Malgré ces indices anormaux qui ne se rencontrent que dans certaines familles végétales, la méthode n'a pas perdue de sa valeur.

2°—*Méthode à l'émulsine*

L'émulsine n'est pas un ferment, mais un mélange de plusieurs ferments spécifiques des glucosides β. Son action consiste à mettre en liberté du glucose dextrogyre et à amener un changement de rotation vers la

droite. On mesure la quantité de matières réductrices formées et le changement de rotation. Il existe aussi pour l'émulsine un indice enzymolytique.

Pour faire comprendre plus facilement l'importance de la méthode, nous allons montrer comment peut se faire l'identification de l'oside contenu dans les feuilles de laurier-cerise (Wattiez et Sternon).

On prend tout d'abord la déviation polarimètrique du liquide d'extraction déféqué; supposons que l'on trouve + 2°. Dosons les sucres réducteurs, soit 0, 50gr%.

A une autre quantité de liquide d'extraction, on ajoute de l'invertine, puis après un séjour de 2 jours à l'étuve, on fait une nouvelle lecture polarimétrique, soit 0°.

La différence entre les deux lectures est de $+ 2° - 0° = 2°$.

On dose dans ce même liquide les sucres, soit 1,706%. La différence entre les deux dosages est; $1{,}706 - 0{,}500 = 1{,}206$gr %.

Connaissant les indices enzymolytiques des principaux osides, on peut savoir quel sucre a participé au dédoublement. Dans le cas qui nous intéresse c'est le saccharose dont l'indice est de 603 mmgr. En effet pour un retour de 2° la quantité de sucres réducteurs qui s'est formée devrait être de $0{,}603 \times 2 = 1{,}206$ c'est-à-dire le chiffre que nous avons trouvé plus haut.

On détruit ensuite l'invertine par la chaleur, puis on ajoute de l'émulsine et après un séjour de deux jours à l'étuve, on examine le liquide. A l'examen polarimètrique, on a une déviation de + 3°. D'où une augmentation de $+ 3° - 0° = 3°$.

Le dosage des sucres réducteurs donne 2,283gr, d'où une différence de $2{,}283 - 1{,}206 = 1{,}077$, augmentation qui correspond à un retour de 3° polarimétriques. L'indice enzymolytique sera donc de $\frac{1{,}077}{3} = 0{,}359$. Ce chiffre correspond à l'indice du prulaurasoside, oside contenu dans les feuilles du laurier-cerise.

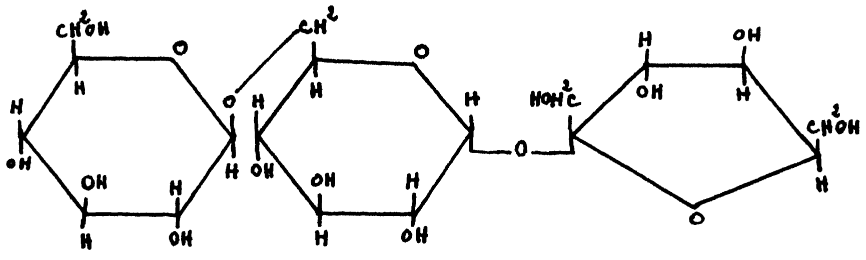
Ainsi en combinant l'action de l'invertine et de l'émulsine, on peut avoir des indications très précises sur les osides contenus dans une plante. Désormais plus de recherches stériles, plus de travaux livrés au hasard dont les résultats sont souvent négatifs. Un simple examen préalable suffit à nous renseigner. De cette façon en 1921 on avait réussi à découvrir et isoler des hétérosides dans 56 espèces. Bourquelot lui-même extrayait 15 hétérosides nouveaux et sur la fin de sa vie, il disait avec justesse avoir tracé du travail pour des générations de chimistes et de physiologistes. De plus il réhabilitait nombre de plantes qui avaient été bannies de la pharmacopée un siècle auparavant, et il montrait que nombre de végétaux de la médecine populaire contenaient des principes actifs qui sont désormais inscrits au Codex.

A côté des résultats dont a bénéficiée la science pharmaceutique, il convient de signaler l'importance de la méthode dans l'étude de la constitution des osides.

Pour cela reportons-nous à un article de Bridel au sujet de l'étude par Bourquelot et Hérissey sur la constitution du gentianose. Ce dernier est

formé par l'union d'une molécule de fructose et de deux molécules de glucose.

Gentianose



L'hydrolyse de ce composé peut être réalisée en deux temps par les acides suivant leur concentration. A la concentration de 2 pour 1000, il y a mise en liberté de fructose tandis que les deux molécules de glucose restent unies pour former du gentiobiose; avec une concentration de 30 pour 1000 le gentiobiose est hydrolysé en deux molécules de glucose. La même action peut être réalisée par l'invertine et l'émulsine: l'invertine met en liberté le fructose et l'émulsine les deux molécules de glucose. Si on arrive au même résultat final, il existe toutefois une différence dans la marche de l'opération. Ainsi, quelque soit la concentration de l'acide, on ne peut jamais arriver à hydrolyser le gentianose en mettant d'abord en liberté le glucose, c'est toujours le fructose qui est libéré le premier. On ne peut donc pas avoir une idée sur le mode d'union du glucose et du fructose dans le gentianose.

Avec les ferments tout est différent. Bridel et Bourquelot ont montré que par action de l'émulsine sur le gentianose., il y a libération d'une molécule de glucose, et l'autre molécule de glucose reste unie au fructose de façon à donner du saccharose qui a été obtenu à l'état cristallisé. Les ferments permirent donc d'élucider la constitution du gentianose.

A la suite de l'impulsion donnée par Bourquelot aux méthodes biochimiques, l'utilisation des ferments comme réactifs de laboratoire se généralisa, et l'effort porta sur d'autres ferments.

Un élève de Bourquelot, Vintilesco employa la myrosine, ferment répandu chez les crucifères, comme agent d'hydrolyse des hétérosides sulfurés.

En 1926 Bridel et Charaux utilisèrent un produit extrait des graines de rhamnus, qu'ils appelèrent rhamnodiastase. On ne connaît pas exactement les ferments qui s'y trouvent contenus, mais on sait qu'elle agit d'une façon analogue à l'émulsine, en libérant une partie non-glucidique et un ose qui n'est pas du glucose β mais un diholoside (primevèrose, rutinose, vicianose) ou un triholoside (rhamninose, robinose).

Plus récemment Mlle Bourdouil en étudiant la poudre de pancréas a montré qu'il était possible de l'utiliser pour la recherche du maltose, car on sait que le suc pancréatique contient de la maltase. Il faut remarquer que cette poudre agit aussi sur d'autres principes grâce à une amylase, une lipase et une protéase.

Enfin la méthode biochimique a permis la synthèse de plusieurs corps. Ce problème avait déjà été entrevu par Croft Hill, qui en mettant une macération de levure en présence d'une solution concentrée de glucose réussit la transformation d'environ 16% de glucose en disaccharides. Bourquelot et Bridel apportèrent des preuves incontestables de la réversibilité des réactions dues aux diastases. Grâce à l'émulsine dont la résistance à l'alcool est assez prononcée, ils réussirent à opérer la synthèse de toute une série de β glucosides. Ils ont montré que c'était la même diastase qui était capable de provoquer la réaction d'hydrolyse et la réaction de deshydratation. On a ainsi réussi à faire du gentiobiose et du cellobiose par action de l'émulsine sur le glucose; de son côté la maltase a fourni des β glucosides.

Cet exposé a montré tout le parti qu'il avait été possible de tirer des méthodes biochimiques et l'étendu des problèmes qui ont pu être posés. Avec une méthode aussi simple, il serait intéressant d'étudier les osides de nombre de plantes qui s'apparentent assez étroitement à certaines espèces européennes. Et même si l'on y rencontrait des principes actifs identiques, est-ce que ceux-ci s'y trouvent dans des proportions semblables, malgré la marche plus rapide de la végétation? D'autre part pour une même plante vivant sous des climats différents une étude sur le métabolisme des glucides, suivant les différentes saisons, serait du plus haut intérêt. Il est à souhaiter que de jeunes chimistes agronomes se lancent dans cette voie, car le sujet a été encore à peine abordé au pays.

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SCIENTIFIC AGRICULTURE

Vol. XVIII APRIL, 1938 No. 8

THE CLIMATE OF SOUTHERN ONTARIO

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[Received for publication January 7, 1938]

The natural vegetation and the agriculture of any region are undoubtedly limited more by its climate than by any other set of factors. Ecologists, pedologists, geographers and others have divided the earth into homogeneous natural regions, the limits of which are chiefly climatic. Actual homogeneity, of course, does not exist over very large areas, but the zones of influence of the chief limiting factors can be determined approximately. For the purpose of the study of crop adaptation and the distribution of varieties of special crops, a much greater wealth of detail is necessary, and large geographic units must be further subdivided. The purpose of the present paper is to analyse the climate of the southern part of the province of Ontario and to delimit the regions in which the conditions are more or less similar. It is hoped that this will be of benefit in the planning of future agronomic adjustments.

I. CLIMATIC FACTORS

All climatic differences are traceable to the differential heating of the earth's surface due to the fact that the sun's rays do not fall with equal intensity upon all parts of the globe. This, together with an inequality in the rates of absorption of heat by land and water, gives rise to air currents or winds, which exert an important influence on the climate.

The chief factors which control the climate of any region are: (1) latitude, (2) altitude, (3) relief, (4) distribution of land and water, (5) proximity to the paths of cyclonic storms.

Latitude

The influence of distance north or south of the equator is seen in the seasonal variation in length of day and in the difference in the amount of heat received from the sun.

Temperature decreases toward the poles for three reasons:

(1) The sun's rays striking at an angle permit the heat to be spread over a larger area than if they fell vertically.

(2) A larger percentage of the heat is absorbed during the longer passage through the air.

(3) Much heat is lost through the long winter nights.

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In general, the average annual temperature is lowered 1° F. for each degree of latitude distant from the equator but this may be modified considerably by local factors such as mountains or large bodies of water.

Altitude

The climatic effects of increased height above sea level are briefly: (1) decreased atmospheric pressure, (2) decreased mean temperature, (3) increased precipitation.

Only a very small proportion of the sun's heat is absorbed during its passage through the atmosphere; and it is only the denser lower layers, containing dust, carbon dioxide and water vapour, which are appreciably warmed, chiefly by radiation from the earth. At higher levels there is less of this blanketing effect, and although just as much heat may be received, it is much more rapidly lost. The average decrease in mean temperature is about 1° F. for each 300 feet of elevation.

Perhaps most important is the effect of altitude on precipitation; the air is cooled in its forced ascent up the slope and by contact with the colder surfaces of higher altitudes, consequently it loses its capacity to hold moisture.

Relief

By relief is meant the difference in altitude of contiguous portions of the earth's surface. A high ridge lying athwart the direction of the prevailing wind will cause intensified precipitation on the windward slope which is compensated by a dry area or "rain shadow" on the leeward side. Such ridges may also serve as a protection from high winds, thus modifying a climate considerably. Deep valleys often attain very high temperatures during the day, but on the other hand, they collect the cold air which drains down the slopes at night and are thus more susceptible to frosts than higher areas nearby.

Distribution of Land and Water

Land surfaces heat up more quickly and cool off more rapidly than does water, hence the presence of large bodies of water tends to stabilize the climate of a region. Climates in which the land influence is predominant are called *continental* while those controlled by the presence of water are called *marine.* The direction and distance from large bodies of water are important, for, in the region of prevailing westerly winds, marine influence is much stronger and more widespread on the eastern margins of large lakes and oceans. Ocean currents also may cause distinct modifications in climate.

Proximity to Cyclonic Storm Belts

Between 35° and 65° N. latitude is found the northern zone of westerly winds and cyclonic storms. On its southern boundary is the sub-tropical area of high pressure in which originate the poleward-moving currents of air which eventually become the westerly winds of the region. To the north is a polar area of high pressure from which streams of cold air gravitate to meet the warmer, lighter air mentioned above. The line of contact between these two air masses is a fluctuating one, and great tongues of heavy polar air may push southward, enclosing pockets or eddies of warmer,

lighter, moisture-laden air of tropical origin. From the latter develop the cyclones or "lows" of a weather map, while the areas of high pressure form the anticyclones. The cyclonic storms are carried along by the westerlies, following more or less well-developed storm paths which, through swinging north or south with the seasons, usually leave the continent by way of the St. Lawrence Valley and the Maritime Provinces, thus bringing to Southern Ontario exceedingly variable and constantly changing types of weather. Trewartha (14) gives a well written account of storms and their weather types, in which the latest theories of cyclonic behaviour are discussed.

Climatic Statistics

Descriptions of climate are of necessity based largely on statistics, the factors which most readily lend themselves to measurement being light, atmospheric pressure, temperature, precipitation, humidity and winds. The data upon which this study is based have been derived from the publications of the Meteorological Service of Canada, supplemented by access to unpublished information which is on file at the central office of the Bureau in Toronto. These records have been compiled from the reports of a large number of weather stations the locations of which are shown in Figure 1. Useful information also has been obtained from the publications of the adjoining states, in particular the works of Mordoff (8) in New York and Seeley (10) in Michigan.

In evaluating the biological significance of climate, the most commonly used statistics are those of temperature, moisture and light. Barometric records in themselves are not so important, although the winds which accompany atmospheric changes are often of great influence. In connection with light, the length of day is easily calculated, a few stations record the hours of bright sunshine and of cloudiness, but data on light intensity are very meagre. Temperature is measured in degrees Fahrenheit, and the records are compiled in various ways. Maximums and minimums are recorded on a daily basis and from these the means and the monthly and annual averages are calculated. Precipitation is measured in inches, monthly and yearly totals and averages being stated. Snowfall is measured in inches and converted to rainfall values on the basis of a ten-to-one ratio, which, however, may be a source of considerable error since the density of snow is extremely variable. Relative humidity is calculated from the difference in the readings of wet and dry bulb thermometers, usually taken two or three times a day at stated hours. Wind observations include direction, duration and velocity.

Classification of Climate

Temperature and precipitation values are the criteria most commonly used in the classification of climate, and numerous world schemes have been proposed which differ only in the arbitrary standards used in the definition of the regional climates. Botanists and plant geographers make use of vegetation as a means of describing climatic zones, giving us such concepts as tundra, northern forest, and prairie climates. The work of Schimper (9) is a classic in this field. To these concepts meteorologists and others have attempted to give more precise definition in terms of phys-

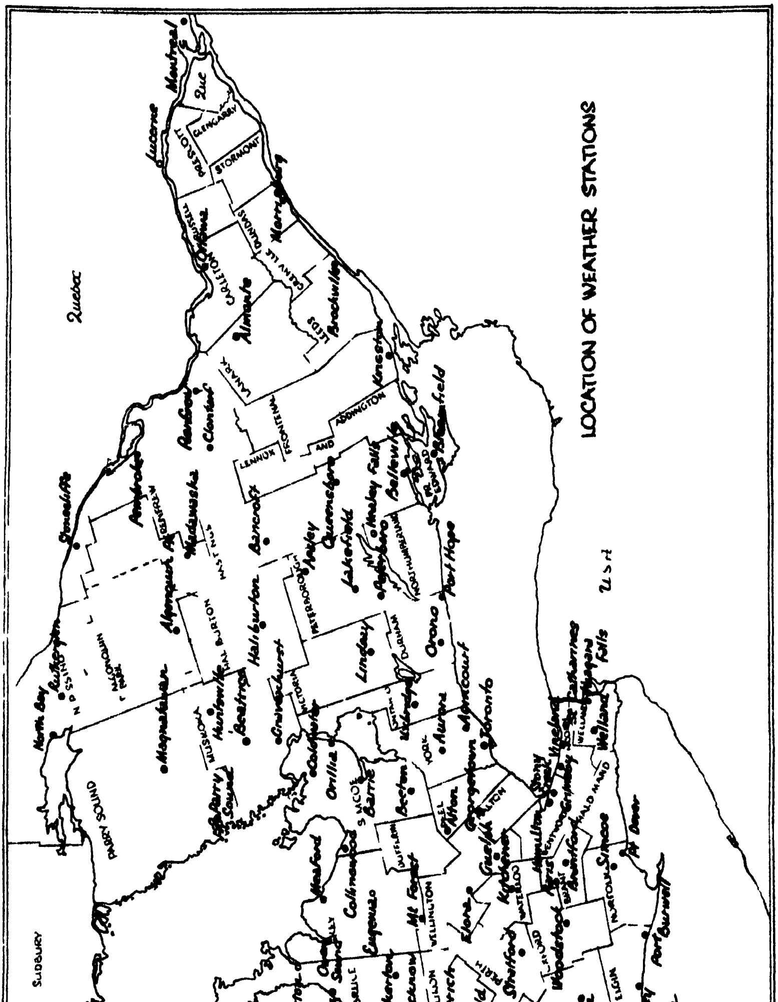

FIGURE 1. Location of weather recording stations in Southern Ontario.

ical phenomena. It is often the case, however, that, what to the physicist is a most appropriate dividing line, seems to have little or no biological significance.

To the agriculturist the question of homoclimes, or similar climates, is an important one, and it will be of interest to examine some of the climatic classifications in order to discover those parts of the earth which are reputed to have climates similar to our own.

The dean of modern climatologists is Köppen (5). His criteria are the temperatures of the warmest and the coldest months and the seasonal distribution of rainfall. In his scheme the whole of southern Canada east of Alberta is defined as having a sub-arctic climate with sufficient precipitation in all months. This type of climate prevails also in Poland, Czechoslovakia, Hungary and Central Russia.

Jones and Whittlesey (3) classify the climate of most of southern Canada west of Montreal in the humid continental type with short summers. It is quite akin to the type of climate which is found in a long belt stretching eastward from Germany and southern Sweden and including the most important grain growing regions of Europe. Manchuria and northern Japan are reported to have a similar type of climate.

Stamp (11) would classify the climate of southeastern Canada and the New England states as a separate type, the Laurentian, but points out that it is similar to the "cool temperate oceanic climate" of northwestern Europe as well as that of Manchuria.

Thornthwaite (12, 13) has recently presented a new quantitative classification, modelled after that of Köppen, in which the factors considered are: (1) precipitation effectiveness, (2) temperature efficiency, (3) seasonal distribution of effective precipitation. The factor for precipitation effectiveness, or the P-E index, is based upon the ratio between average monthly precipitation and average monthly evaporation from a free water surface, and is a rather useful method of indicating comparative aridity. The T-E index, or temperature efficiency factor, is based upon the monthly mean temperature above 32° F. arbitrarily divided by four. In this scheme, which was devised on the basis of North American data, a total of thirty-two types of climate can be located on the surface of the globe. The climate of the region around the Great Lakes is designated as humid, microthermal with adequate rainfall at all seasons.

It is of interest to note that soil characteristics are in the main governed by climate; consequently, in a general soil map of the world such as that of Wolfanger (16) the great soil groups correspond to the major climatic divisions. Indeed soil maps frequently contain a degree of detail not found in climatic maps; for instance, Southern Ontario is just about equally divided between the zone of the podsols and that of the grey-brown podsolic soils.

Broad climatic classifications serve to divide the surface of the earth satisfactorily into large divisions which correspond closely to the major agricultural regions. In order to obtain an idea of the variations within regions, and to carry out studies on the adaptation and distribution of special crops or varieties, it is necessary to have a much more intensive study of local climatic differences. With this end in view, the present analysis of the climate of Southern Ontario has been undertaken.

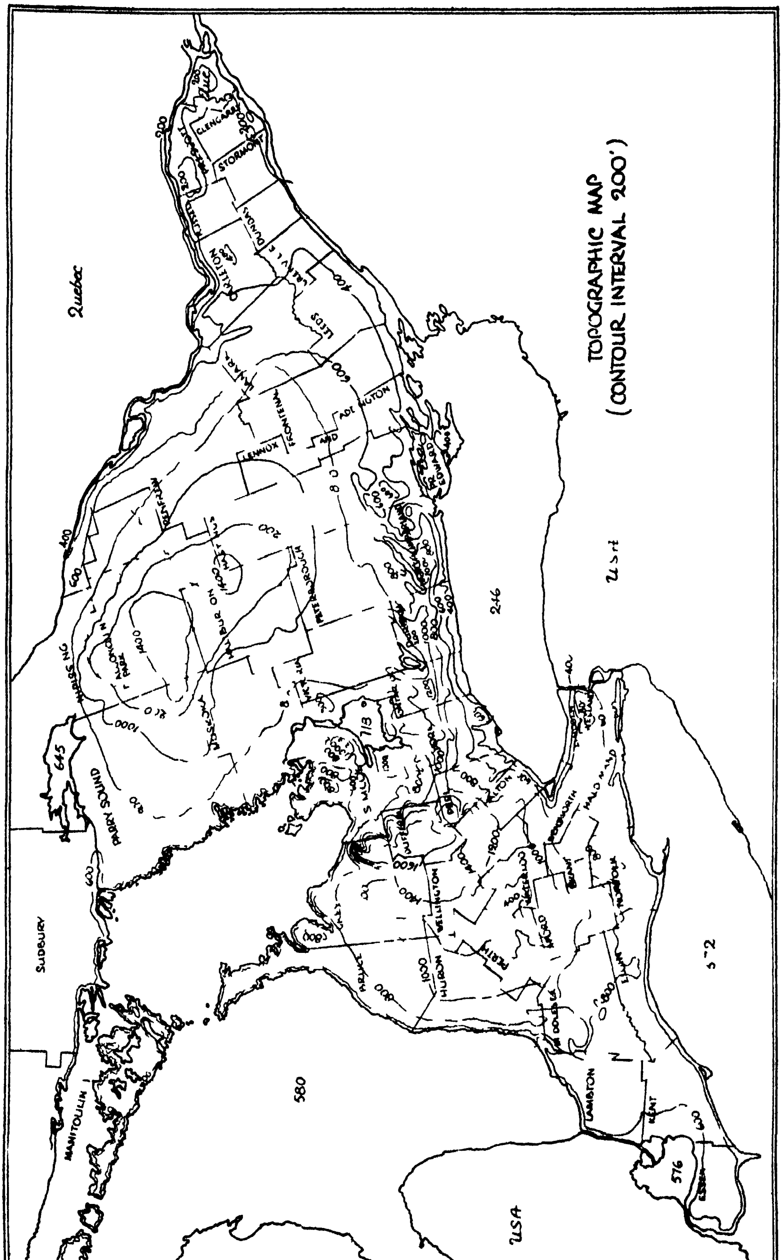

FIGURE 2 Topographic map of Southern Ontario Contour interval 200 feet

II. CLIMATE OF SOUTHERN ONTARIO

Physiography of the Area

The area comprehended by the title, Southern Ontario, is that part of the province lying south of Lake Nipissing and including the island of Manitoulin. It extends over four degrees of latitude from 42° to 46° N., and has a total area of about 50,000 square miles. On the west it is bounded chiefly by Lake Huron and Georgian Bay, on the south by Lake Erie and Lake Ontario, and on the northeast and north by the Laurentian highlands of Quebec and Northern Ontario.

From a geological point of view, it may be stated that the northern half of the area is part of the Canadian Shield and is underlain by the very hard and ancient rocks of the Precambrian era. The southern half is underlain by the softer sedimentary sandstones, shales and limestones of the Paleozoic, and it is in this latter section that most of the soils suitable for agriculture are developed.

Topographically, the area presents several salient features which appear in Figure 2 which is a contour map of the area. It is surrounded by rather extensive lowlands, a large part of which are covered by the waters of the Great Lakes. Eastward there is the extensive plain of the upper St. Lawrence valley; along the northeast there is the narrower lowland of the Ottawa valley, while at the north there is the lowland area in which is situated Lake Nipissing.

There are two important highland regions with large areas above 1200 feet in elevation. The Western Ontario uplands comprise portions of Bruce, Grey, Huron, Dufferin, Perth, Waterloo and Wellington counties. This area is a huge plateau with its highest portion rising abruptly from the lowlands at the northeast and sloping gradually toward the west and south. The other elevated area is found in the Algonquin Park and parts of adjacent districts; it is not quite so elevated but comprises much rougher country. These upland areas are so situated that they lie athwart the prevailing winds after they have passed over fairly large bodies of water, and the windward slopes are therefore regions of heavy precipitation. On the other hand, the leeward areas are "rain shadows" or areas of lessened precipitation.

The lowlands of the southwest are open to the moderating influence of winds across the lake waters but the lowlands of the east are climatically controlled by land areas and in winter receive the advancing cold waves from both north and east.

It will be seen that the physiography of the region exerts great influence upon the climate, isotherms, isohyets, and isochrons, all tending to parallel the lake shore and to circle the higher land.

The position of the area between 42° and 46° N. is such that it is directly in the path of the strongest westerlies as well as of the majority of the cyclonic storms as they pass across the continent from west to east. In fact, the northern and eastern parts are known to be among the stormiest regions in the world. The passage of cyclones and anticyclones over the area produces weather which fluctuates widely in cycles of from two to five days. A day or two of mild weather, followed by fine and cooler

weather and then rain or snow, repeated over and over throughout the year, produces a very changeable climate.

Length of Day

Southern Ontario is a region of moderate seasonal variation of length of day, lying, as it does, almost midway between the equator and the pole. Figure 3 shows graphically the variations throughout the year on the parallels of latitude which correspond to the south and the north of the area.

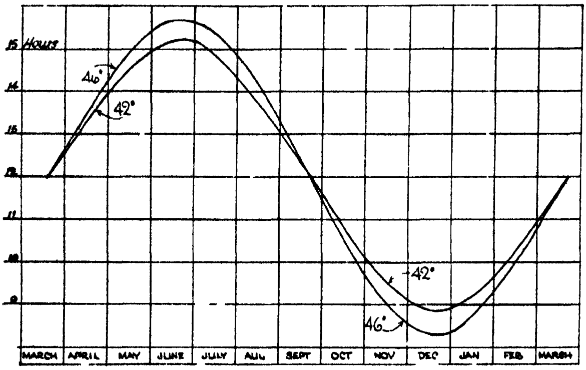

FIGURE 3. Length of day at 42° and 46° N. latitude

From an agricultural standpoint, it is the differences during the growing season which are most important, since the development of the different stages of many plants is closely conditioned by length of day.

Temperature

Temperature is the controlling factor of climate in Ontario and merits considerable detailed study. Temperatures are constantly changing, hence no single value such as mean annual temperature can convey an adequate picture. In order to depict the monthly and seasonal variations together with the modifications produced by physiographic features, the data have been organized and charted on a series of isothermal and isochronal maps, the chief features of which will be discussed in the following paragraphs.

Mean Annual Temperature

Annual temperatures, since they are an average of all the variations which occur, are distinctly limited in their usefulness, their chief value being for general comparison of regions. In Figure 4 it is shown that the variation in Southern Ontario is from 48° F. in the extreme southwest to 38° in the Algonquin Park.

Winter Temperature

Winter temperatures, Figure 5, are the average of the means of the months of December, January and February. They are important since they constitute the critical factor governing the survival of many of the more tender perennial crops. Leamington and Pelee Island with an average of 26° during this period is the warmest section of Ontario. The only parts of the Dominion with milder winters are the west coast of British Columbia and the southwest tip of Nova Scotia. Northward and eastward the winters are much colder, with an average of 13° at Ottawa and 11° in the Nipissing district. Lake influence is very marked, especially in the Niagara Fruit Belt and along the shores of Lake Huron and Georgian Bay where there are prevailing on-shore winds.

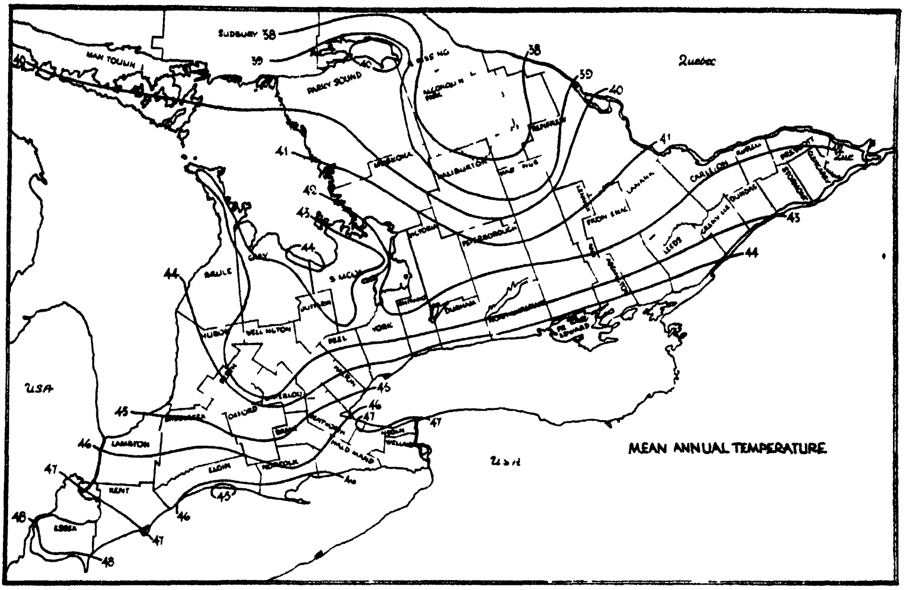

FIGURE 4. Mean annual temperatures in Southern Ontario.

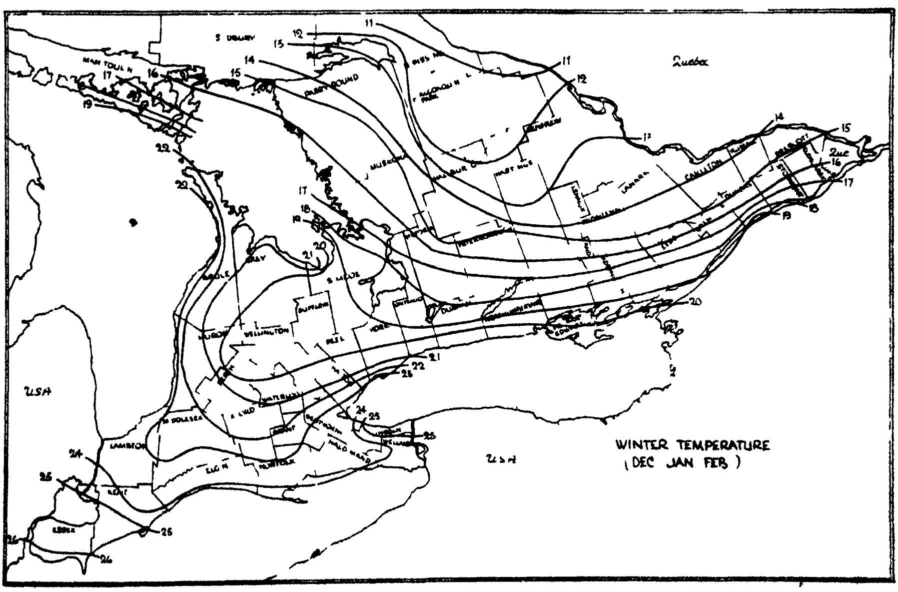

FIGURE 5. Mean winter temperatures in Southern Ontario.

Spring Temperature

Spring temperatures, Figure 6, are the average of the monthly means for March, April and May, and are useful in depicting the relative earliness of the season in the various regions. Spring opens first in the area around Leamington, Harrow and Windsor and is latest in Manitoulin, Algonquin Park and the highest part of Grey County. Along the shores of Lake

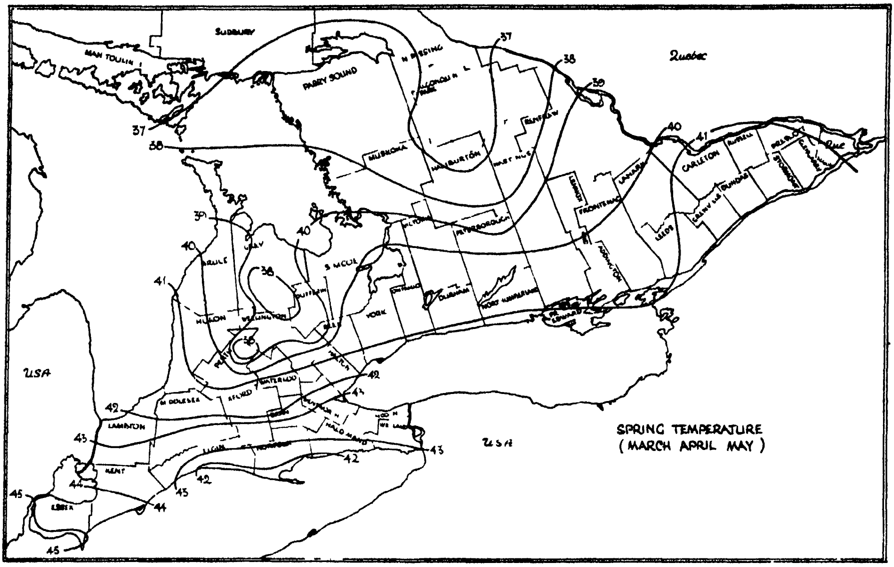

FIGURE 6. Mean spring temperatures in Southern Ontario.

Huron and Lake Erie there is a noticeably cooler strip where the winds now bring air over water that is cooler than the land. It is of interest, also, that the eastern counties which experience much more severe winters have spring temperatures three degrees higher than the uplands of north Wellington, Grey and Dufferin counties.

Summer Temperature

Isothermal lines of average temperature during the months of June, July and August, Figure 7, show that there is less variation at this period than in any other season. Pelee Island with a temperature of 71° is the hottest spot; Kent and Essex counties are similar to the Niagara Fruit Belt, while a uniform zone with an average temperature of 66° extends from the southern end of Lake Huron to the Quebec border. Manitoulin Island and Algonquin Park are the coolest places, with an average of 62°.

Autumn Temperature

Figure 8 is based on the average of the monthly means for September, October and November. The temperatures at this season, but particularly in September and October, are important to many late crops. Here again, the influence of the lakes is evident. The water cools off more slowly than the land; consequently the shore regions have a warmer climate at this time of the year than places farther inland. Furthermore, inland areas usually have a higher altitude and this tends to increase the temperature

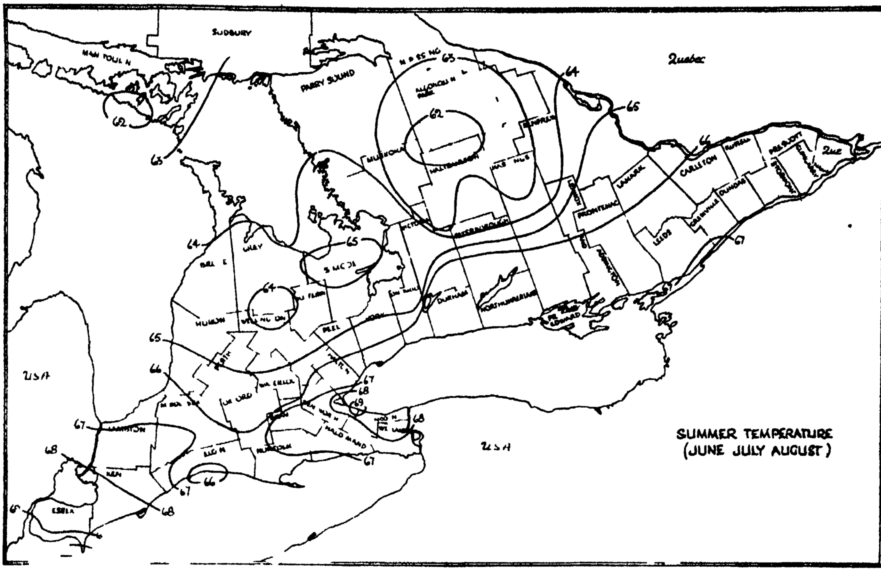

FIGURE 7 Mean summer temperatures in Southern Ontario.

difference. Two cases in point are the western uplands, typified by Dufferin county, and the Algonquin Park, both of which stand out as "lows". Around the Great Lakes the isotherms are roughly parallel to the shore, thus giving Collingwood, Southampton, Toronto and Kingston practically the same average temperature. Even the smaller inland lakes, such as Nipissing, are not without their effect as is shown by the temperature at North Bay.

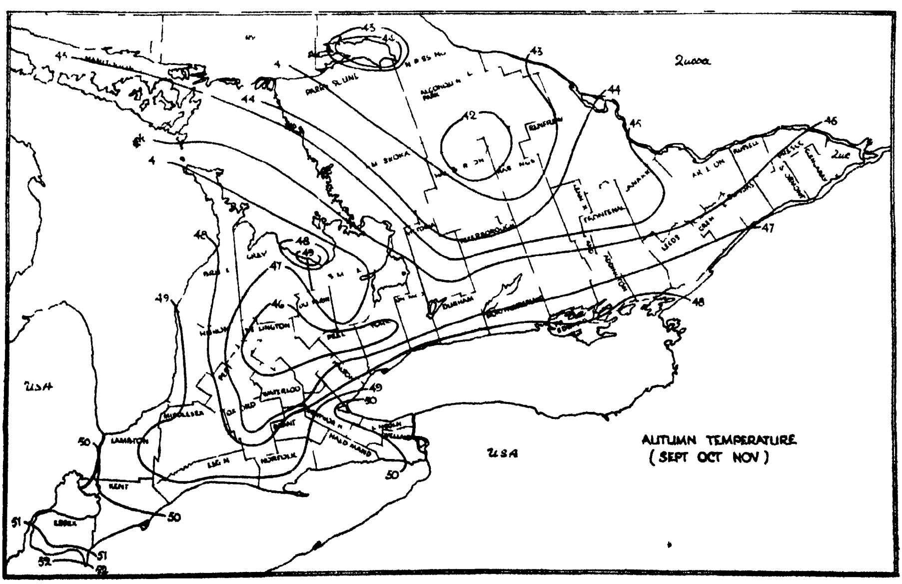

FIGURE 8. Mean autumn temperatures in Southern Ontario

Monthly Mean Temperature

For many purposes, it may be desirable to supplement the seasonal temperatures with monthly means. Accordingly, Figures 9–20 have been prepared and included for reference purposes but will not be discussed here individually. It is suggested, however, that the January isotherms give a better picture of mid-winter conditions in the various sections than do average winter temperatures, the April isotherms are useful when considering earliness, and July isotherms should be considered in connection with summer temperatures. It is well known, for instance, that the northern limit of the region climatically suited to the production of seed corn coincides with the July isotherm of 70°. Similar correlations can doubtless be made with the data for each month.

Daily Range of Temperature

The daily range in temperature is, in general, the difference between day and night temperatures, and is an important characteristic of climates. It is vitally important in relation to human activity, especially in hot climates, where the daily range may be several times that of the annual range; even in Southern Ontario, the desirability of spending holidays in a place where one may sleep comfortably under blankets in July and August, is a factor not to be overlooked.

Mean temperatures are calculated by adding the maximum and minimum daily temperatures and dividing by two; thus a mean of 70° may represent temperature conditions varying from 60° to 80° or from 68° to 72°. Such considerations bear an important relationship to the frequency of frosts or of temperature extremes.

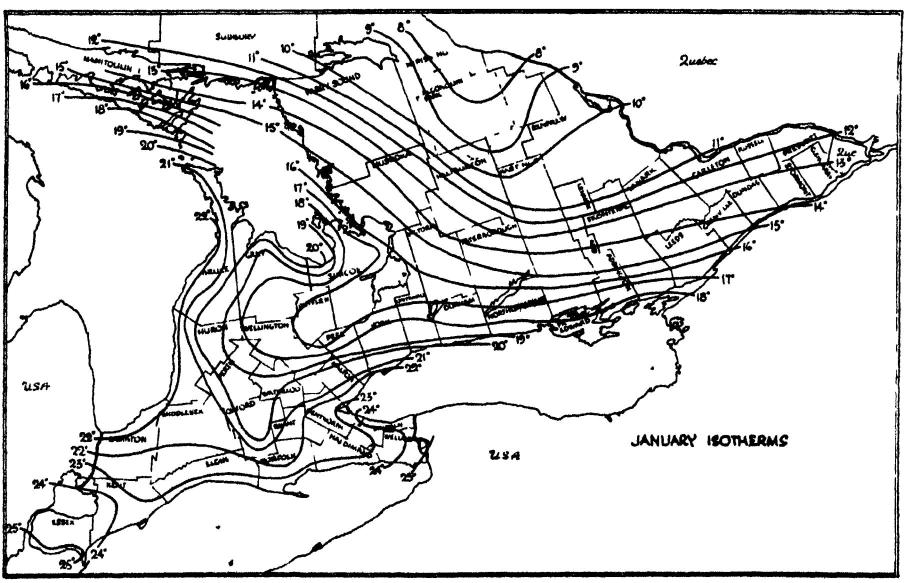

FIGURE 9. Isotherms of mean temperature for January in Southern Ontario.

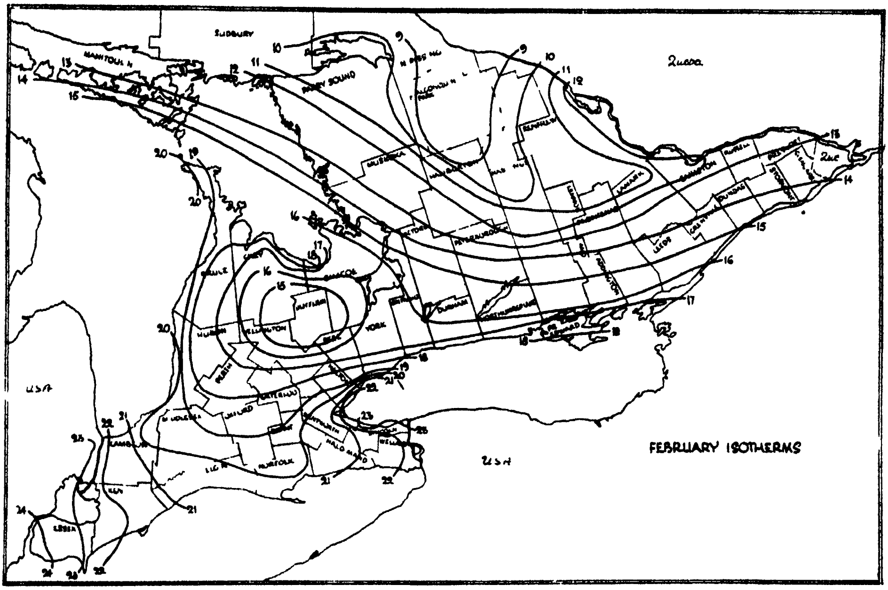

FIGURE 10. Isotherms of mean temperature for February in Southern Ontario.

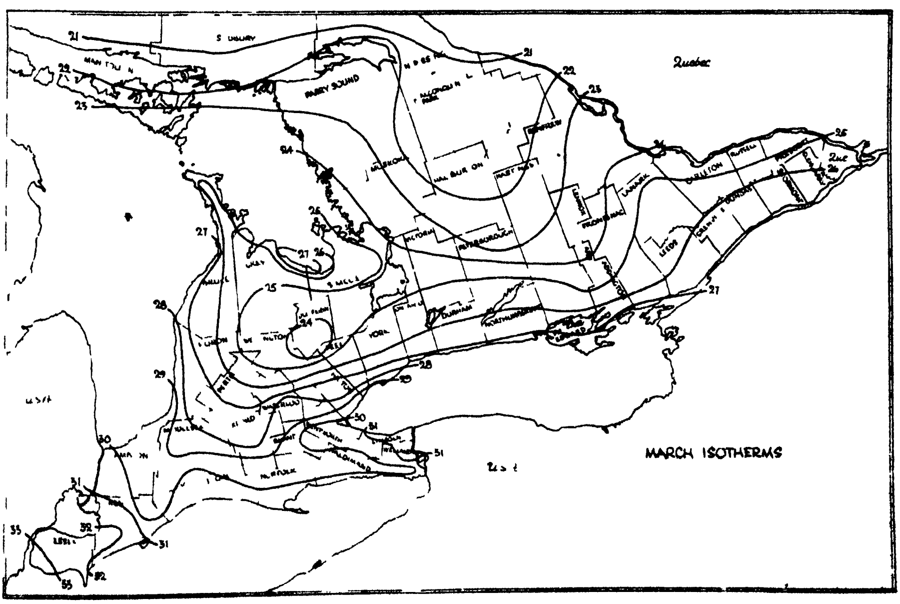

FIGURE 11. Isotherms of mean temperature for March in Southern Ontario.

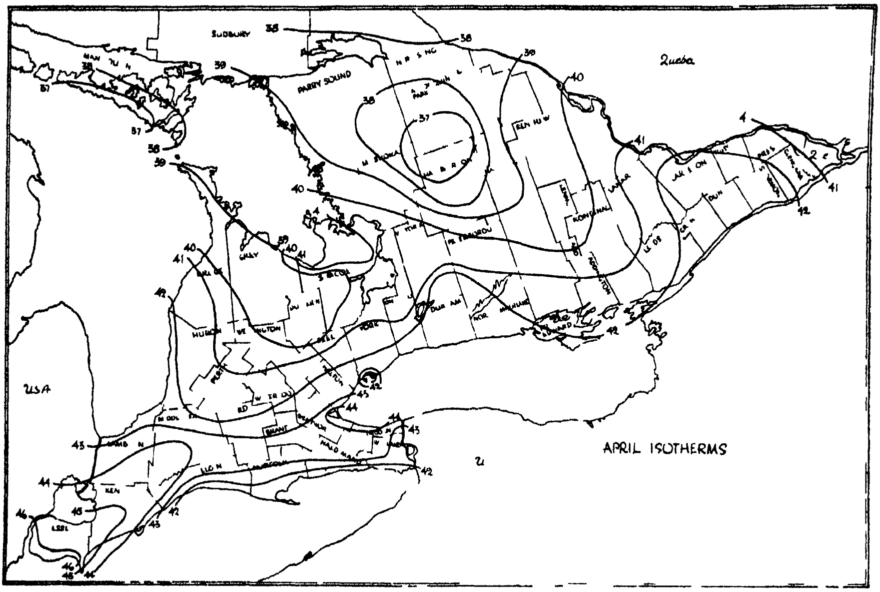

FIGURE 12 Isotherms of mean temperature for April in Southern Ontario

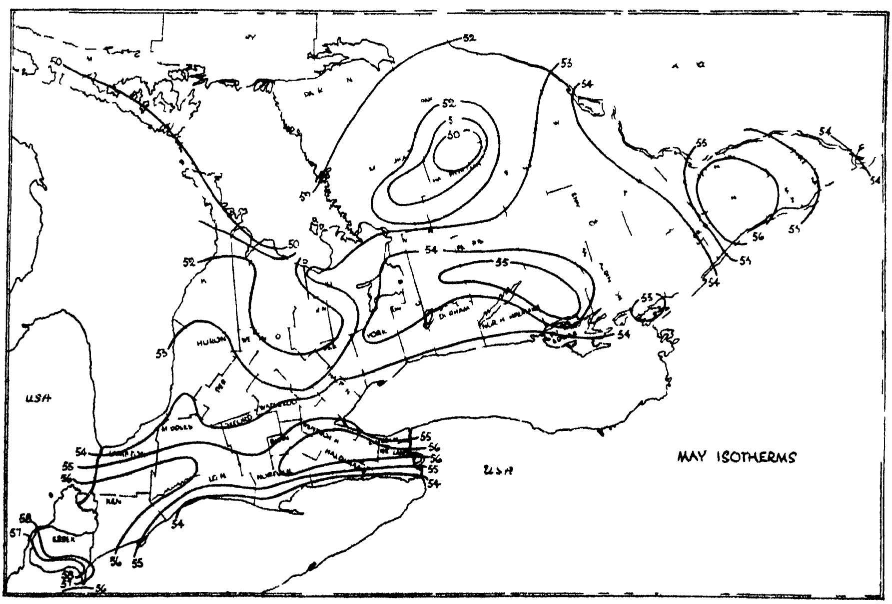

FIGURE 13. Isotherms of mean temperature for May in Southern Ontario.

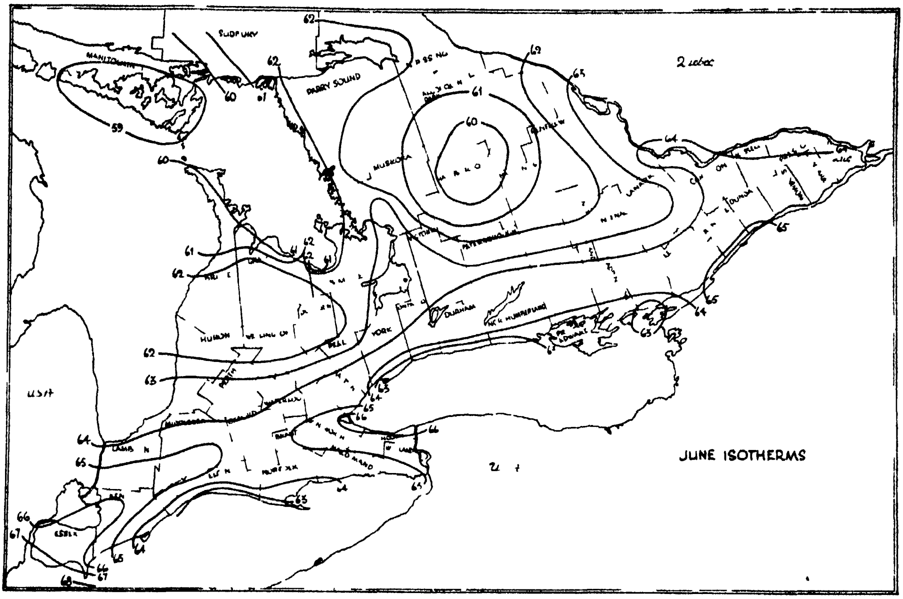

FIGURE 14 Isotherms of mean temperature for June in Southern Ontario

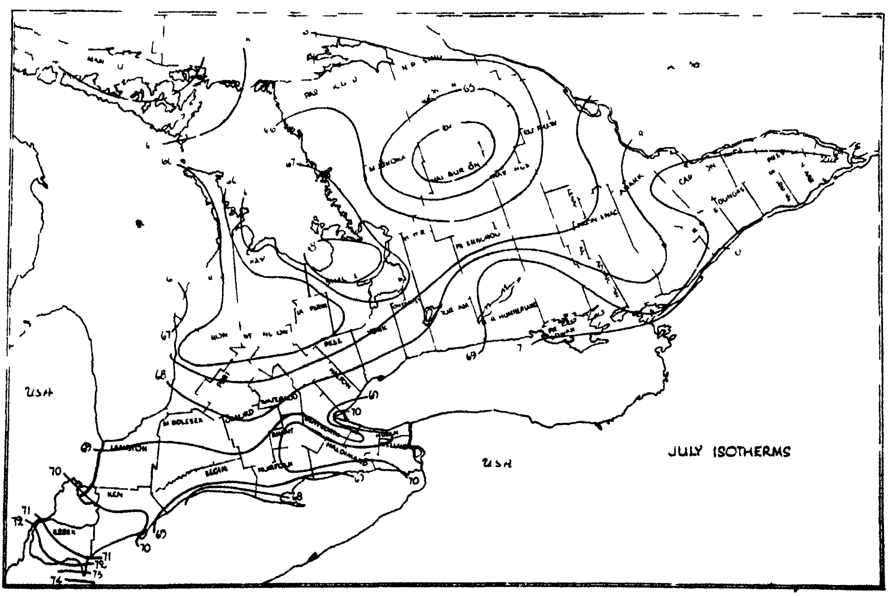

FIGURE 15. Isotherms of mean temperature for July in Southern Ontario.

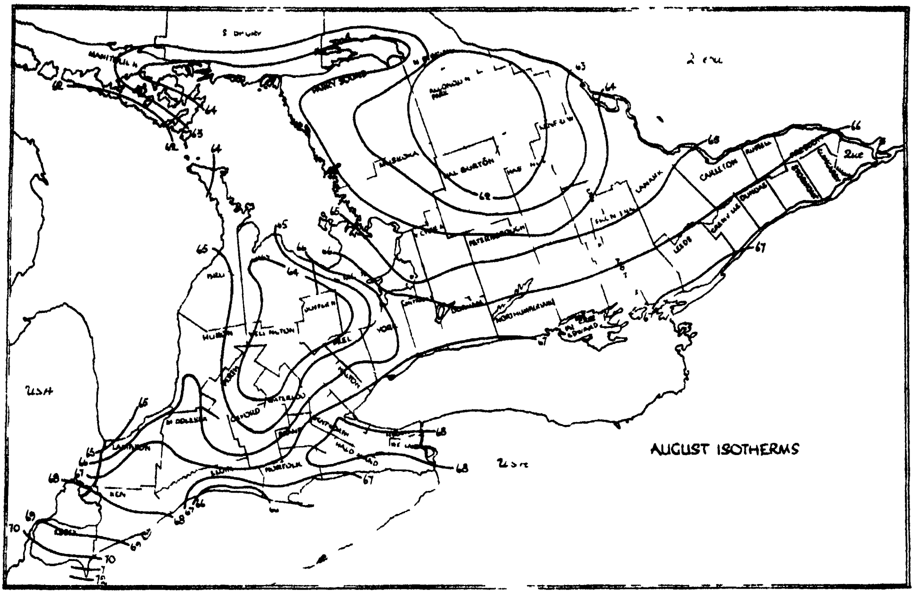

FIGURE 16. Isotherms of mean temperature for August in Southern Ontario

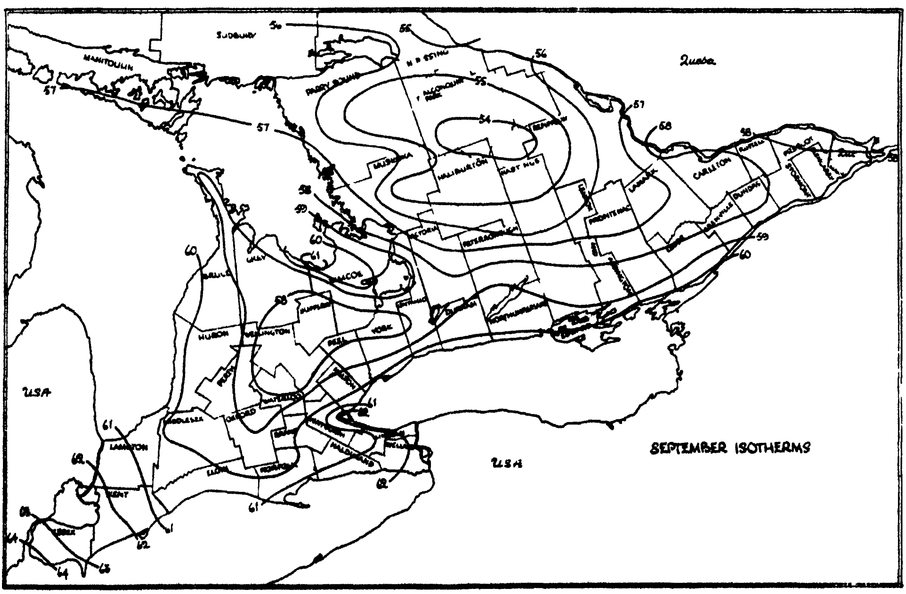

FIGURE 17. Isotherms of mean temperature for September in Southern Ontario.

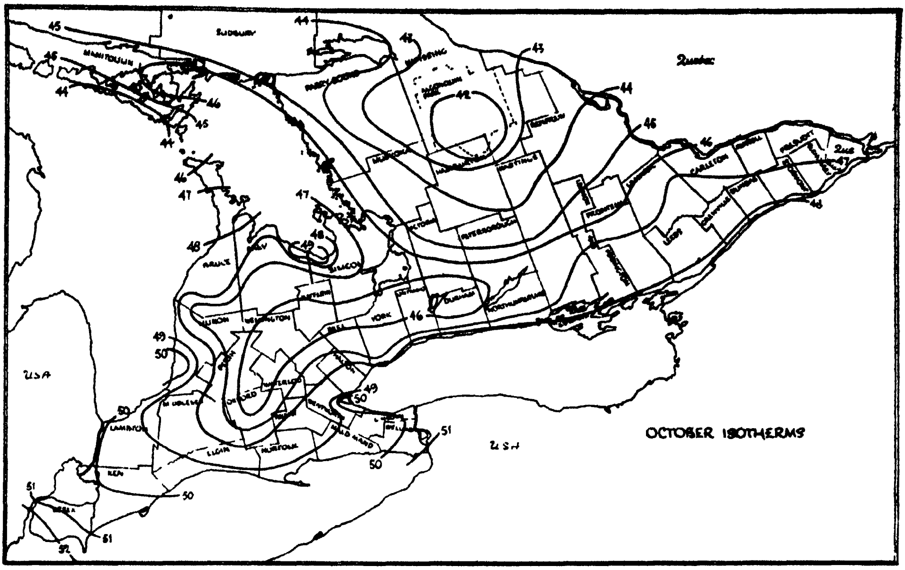

FIGURE 18. Isotherms of mean temperature for October in Southern Ontario.

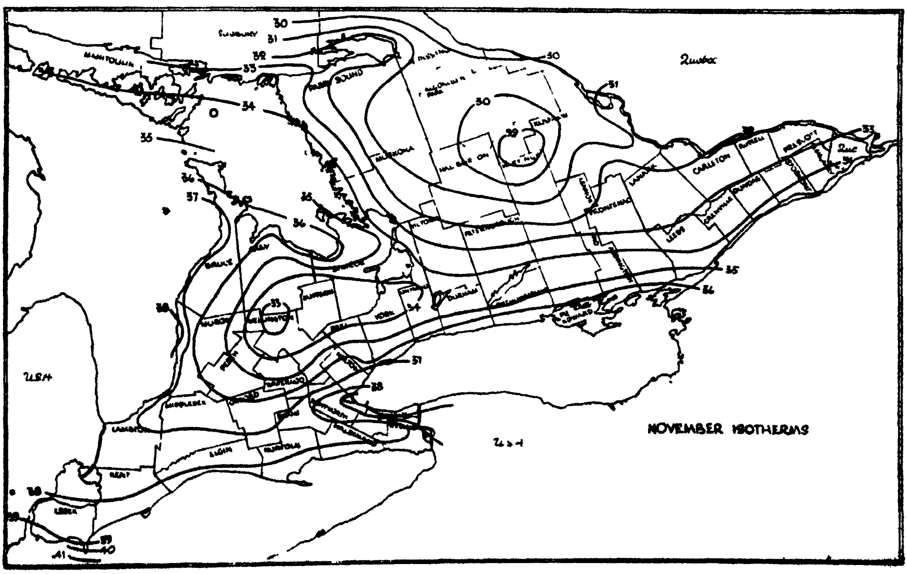

FIGURE 19. Isotherms of mean temperature for November in Southern Ontario.

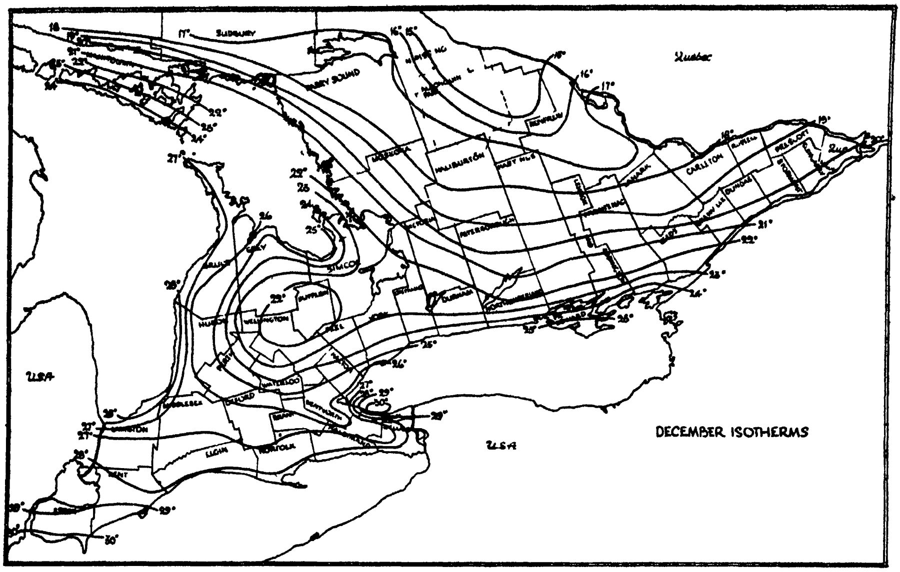

FIGURE 20. Isotherms of mean temperature for December in Southern Ontario.

Mean annual daily ranges of temperature are presented in Figure 21. Here again the ameliorating influence of the Great Lakes is evidenced by the way in which the lines arrange themselves parallel to the shores. In the summer even the small inland lakes have a local effect in preventing wide daily fluctuations in temperature. The widest range occurs in the

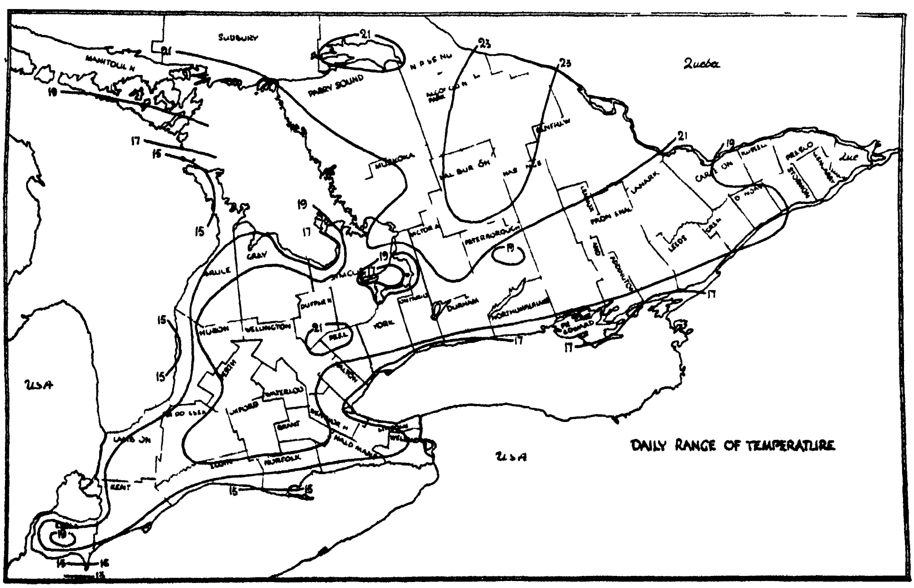

FIGURE 21 Annual mean daily range of temperature in Southern Ontario.

areas of highest altitude, and away from the lakes; at Madawaska, for instance, there is a range of 28° in July whereas on Pelee Island the corresponding figure is 15°.

Extremes of Temperature

In Figures 22 and 23 are shown the lowest and the highest temperatures on record. It is interesting to note that most of the former were registered during the month of February, 1934, while the latter occurred chiefly in July, 1936. The low temperature records are more regularly distributed than are those of the extreme high temperatures. It is notable, however, that the effect of Lake Huron and of higher altitudes prevents the occurrence of extreme heat in the north-west and north. Southampton has never recorded a temperature above 96°, while the highest temperature on record, 106°, occurred at Chatham, Grimsby (Rock Chapel) and London, all located in the south and away from the maximum influence of the lakes.

The lowest recorded temperature in the region is −50° which occurred at Madawaska, while a low of −12° at St. Catharines shows that the Niagara Fruit Belt is the most favoured part of the province in this repsect. The Leamington area which has equal or greater advantages, otherwise, has occasional low temperature records of −20°, which is one reason why peaches are more easily grown in the Niagara Fruit Belt. Eastern Ontario and the western upland region are on a par with records of −35° to −40°, while the areas adjacent to Lake Huron and Lake Ontario do not experience temperatures below −30° to −35°.

The Growing Season

The term "growing season" obviously refers to the period in which plant growth occurs. Strictly speaking, each plant has its own growing season; some plants are more resistant to cold than others and the limits of their growing seasons will vary accordingly. However, some measure of this period is necessary in a description of climate, and in the absence of sufficient phenological data some statistical basis must be adopted. In some cases, the term "growing season" is confused with "frost-free" period. Merriam (6), and Kincer (4), use the mean of 6° C. as a vegetative date. The British Meteorological Service (1) use 42° F. as a base in the calculation of accumulated temperatures. Whitson and Baker (15) also use 42° F. in calculating the distribution of "effective heat" in Wisconsin. The date of the occurrence of the mean of 42° F. has therefore been chosen as the beginning of the growing season for the purposes of this paper. It is highly significant in this regard to note that by correlating mean temperatures with Dr. A. H. McKay's excellent phenologcial data from Nova Scotia, it is found that the date of first plowing regularly coincides with that of 42° mean temperature. Calculated on this basis at weekly intervals, Figure 24 shows the beginning, Figure 25 the end, and Figure 26 the length of the growing season in Southern Ontario.

The earliest area is around Leamington, Harrow and Windsor; the Niagara Fruit Belt and the counties of Kent, Essex and Lambton are about a week later; a broad belt extending from Lake Huron to the Quebec border is another week later, followed by the western uplands, Muskoka, Parry Sound and Haliburton districts; and the latest of all are Algonquin Park and Manitoulin Island which are four weeks later than Leamington.

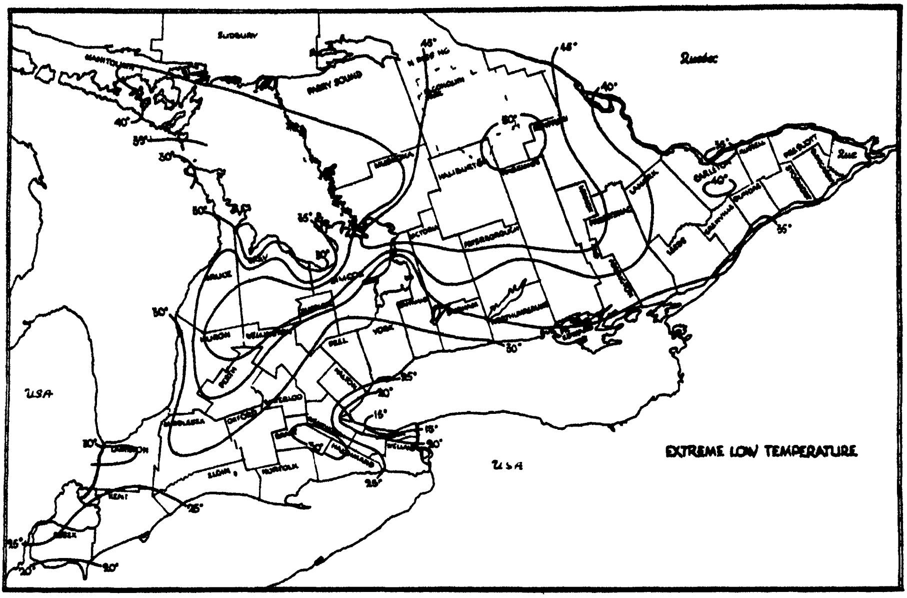

FIGURE 22. Isotherms of lowest temperature on record in Southern Ontario.

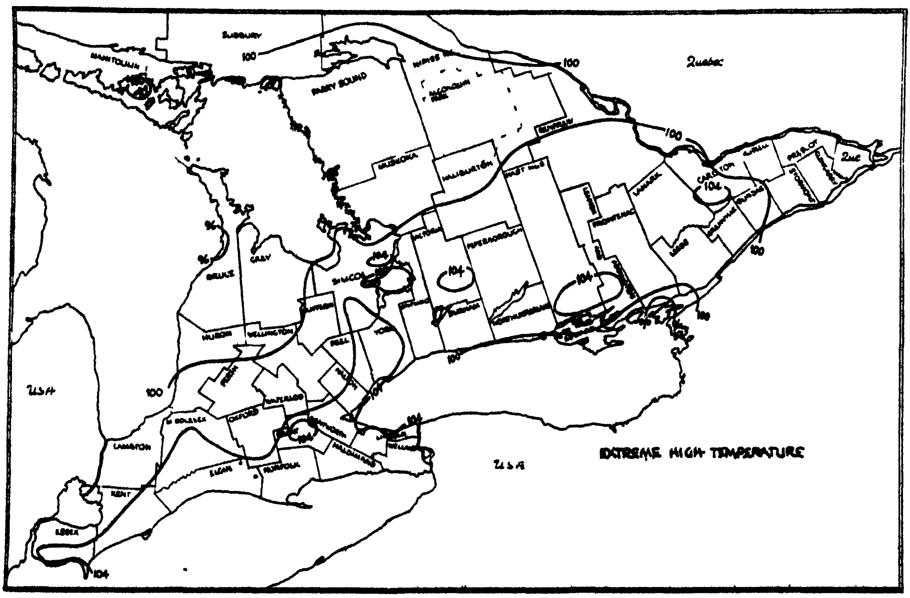

FIGURE 23. Isotherms of highest temperature on record in Southern Ontario.

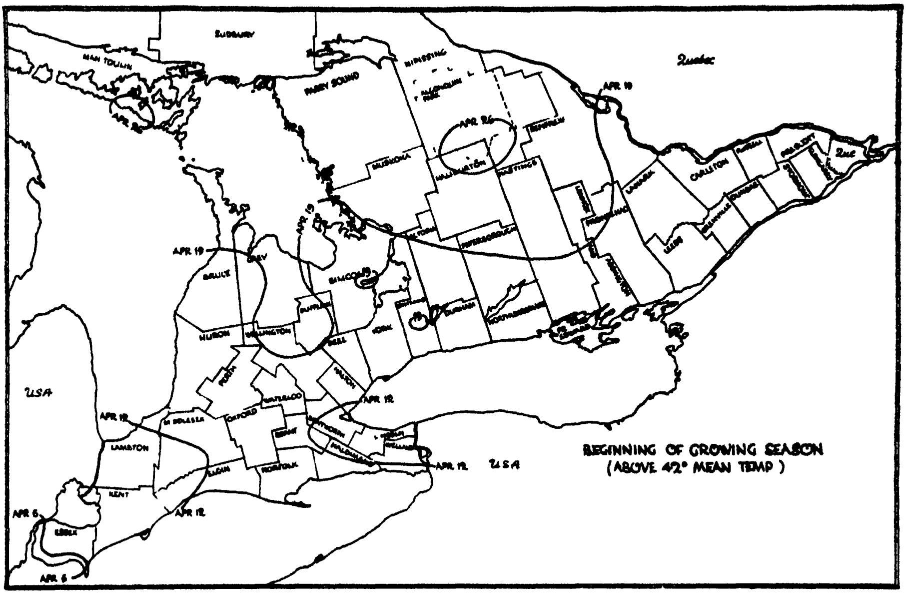

FIGURE 24. Average date of the beginning of the growing season in Southern Ontario.

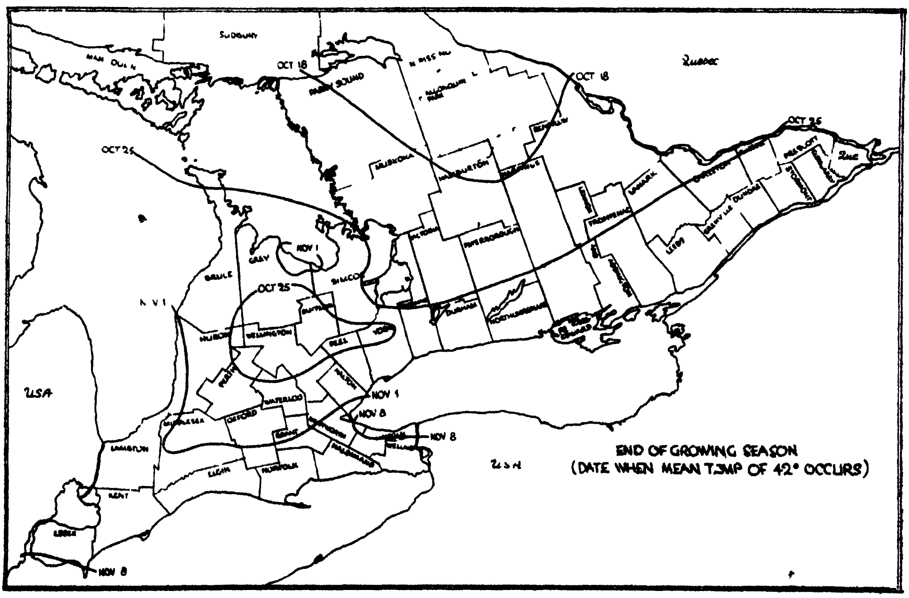

FIGURE 25. Average date of the end of the growing season in Southern Ontario.

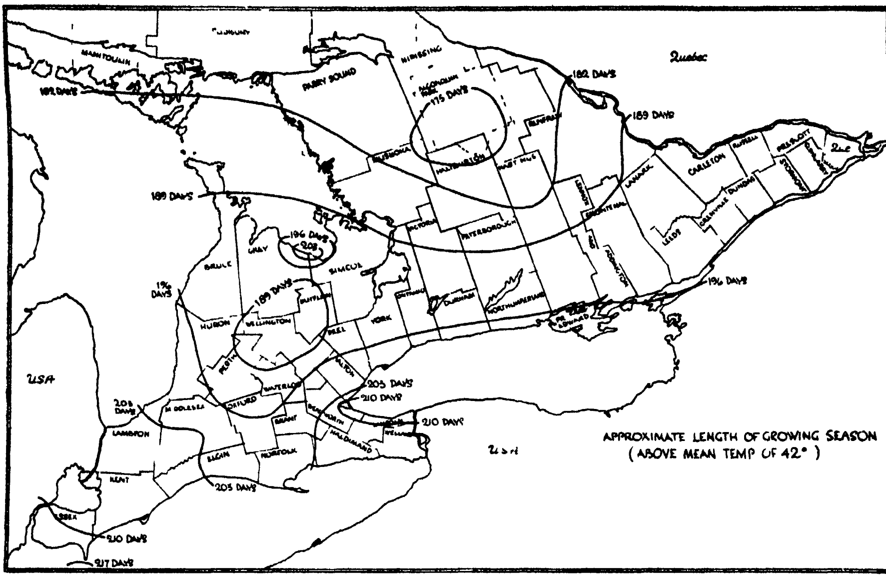

FIGURE 26. Average length of the growing season in Southern Ontario.

In the autumn the process is reversed. The season comes to a close in Algonquin Park about the middle of October but is progressively later southwards until the Leamington area is reached, where there is slightly more than three weeks longer of open weather.

The length of the growing season is, of course, set by the spring and fall dates. It varies from 172 days in Algonquin Park to 216 at Leamington and 217 on Pelee Island, a difference of more than six weeks.

Frosts

The observers at the meteorological stations record killing frosts; that is, frosts which cause damage to plants, but in cases where such record has not been made the last recorded temperature of 33° is taken instead. In Southern Ontario there are many stations reporting frost dates but many of them have only intermittent or short-time records. There is in addition the personal factor of the observer, for one man's idea of a killing frost is not necessarily the same as that of another; certainly there are, in the recorded data, discrepancies in the average figures for adjacent stations which cannot well be explained.

It was felt, therefore, that some statistical method for smoothing out these discrepancies was required. Since it was obvious that the average dates from long-time stations are more reliable, an examination was made of the longest available records throughout Ontario and the northern part of New York State. By graphical methods the mean temperatures of the dates of both last spring frost and first fall frost were computed for these stations. In the same way the mean daily range of temperature was found for the same dates. It was seen that the mean temperature of the average frost date, in most cases, corresponded closely to 32° plus the mean daily range of temperature. This relationship was then used in the construction of the isochronal charts shown in Figures 27, 28 and 29.

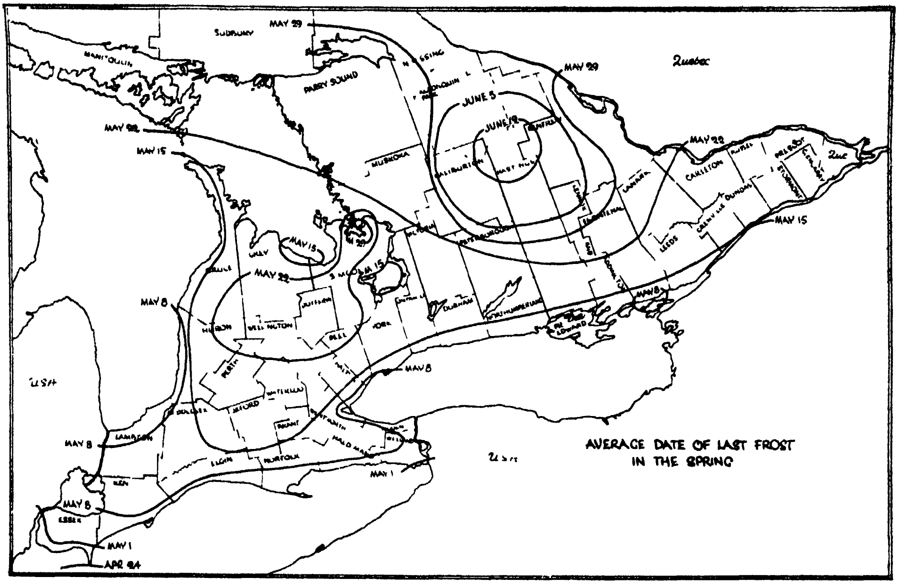

FIGURE 27. Average date of the last frost in the spring in Southern Ontario.

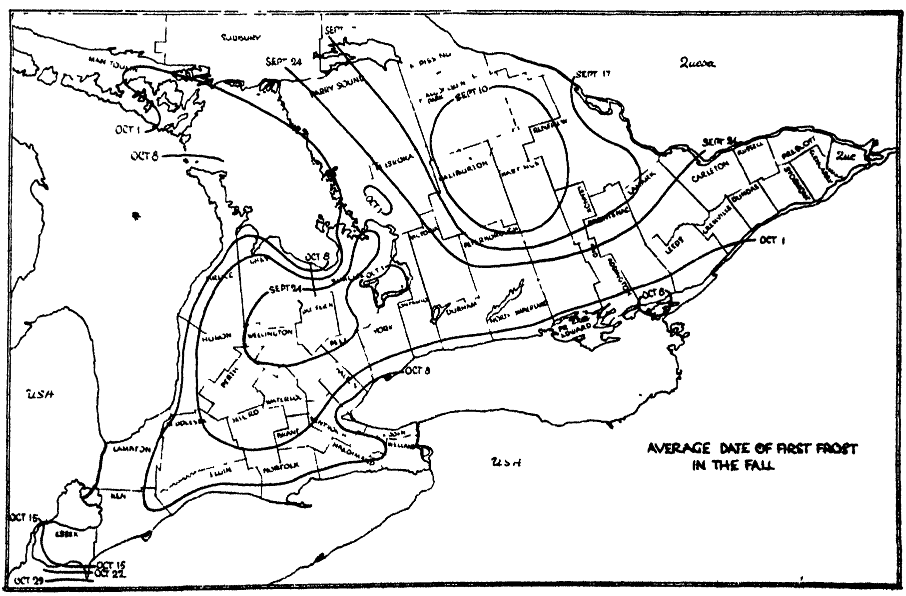

FIGURE 28. Average date of the first frost in the fall in Southern Ontario.

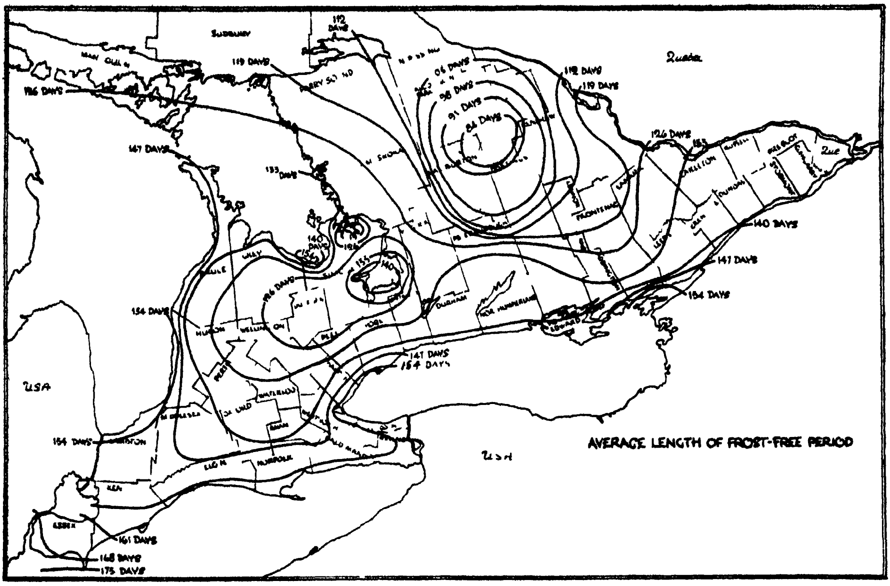

FIGURE 29. Average length of the frost-free period in Southern Ontario.

It must be borne in mind that there is considerable variation in the frost dates, especially in those areas farthest removed from the influence of the lakes. Apart from this there are also local variations due to topography. The "lay of the land" and its effect upon air drainage and therefore upon the occurrence of frost is a factor of importance in choosing sites for special crops. Certain stations, notably Coldwater, are known to be located in frost traps, and while no station exists at Bradford, the occurrence of frost is one of the chief worries of the gardeners on the Holland Marsh.

On Pelee Island the average date of the last spring frost is April 20; in Algonquin Park it is June 15. In fall the average frost date on Pelee Island is November 4, while in the Algonquin Park it is September 10. There is thus an extreme variation in average frost-free period from 175 days on Pelee Island to 78 days in Algonquin Park. It is worth noting that the shores of Lake Huron and Georgian Bay are singularly free from frosts in the fall. Being on the east side of a large body of water this region is more affected by its proximity than, for instance, the north shore of Lake Ontario. It should be stated also that in certain areas, notably Algonquin Park, and even in the western uplands, killing frosts have been recorded in all months of the year.

Precipitation

Although in general the climatologist classifies the whole of Southern Ontario with those regions having adequate precipitation at all seasons, there are differences in rainfall and snowfall, which in a treatise of this sort demand description. However, since critical limits are seldom reached, this factor is of relatively less importance than it is in drier areas such as

the southern parts of the Prairie Provinces or in the interior of British Columbia. Accordingly, only the more important moisture relationships will be discussed in the following paragraphs.

Mean Annual Precipitation

The mean annual precipitation varies from 26.3″ to 40.0″ at the various stations. From a study of the isohyets in Figure 30, it is evident that there is less rainfall over the lakes than on the inland areas sloping

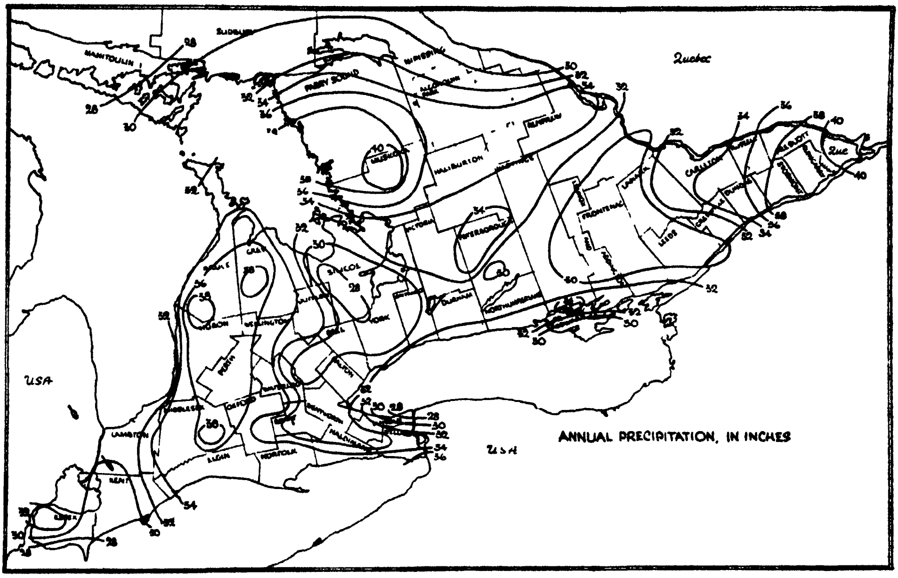

FIGURE 30. Mean annual precipitation in Southern Ontario.

upward from their shores. Manitoulin Island, Pelee Island, the Niagara Peninsula and Prince Edward County all show this tendency. The heaviest precipitation occurs on the west slopes of the uplands facing Lake Huron and Georgian Bay, while "rain shadows" or drier areas are found to the leeward. The extreme eastern part of Ontario is also an area of heavy precipitation.

At all stations the distribution throughout the year is fairly uniform, although the late winter and spring months receive slightly less than those of the rest of the year. The greatest precipitation occurs in December at some stations while in others it is in July; contrary to all popular conceptions of "April showers", this month is generally the driest in the year. The mean monthly rainfall at Bancroft in April is 1.58 inches, while at Parry Sound in December it is 4.54 inches, these figures representing the extremes in this regard. Occasional individual months with 10 inches have been recorded, while it is fairly common to find records of months in which there was none at all.

Mean Annual Snowfall

Snowfall may be regarded as a function of both precipitation and temperature, hence it increases from south to north in Southern Ontario,

with modifications which closely resemble those shown in the map of annual precipitation. In Figure 31 it is seen that at Leamington and in the Niagara Fruit Belt there is less than 40 inches per year, while Owen Sound with 125 inches and Beatrice with 130 inches represent the other extreme.

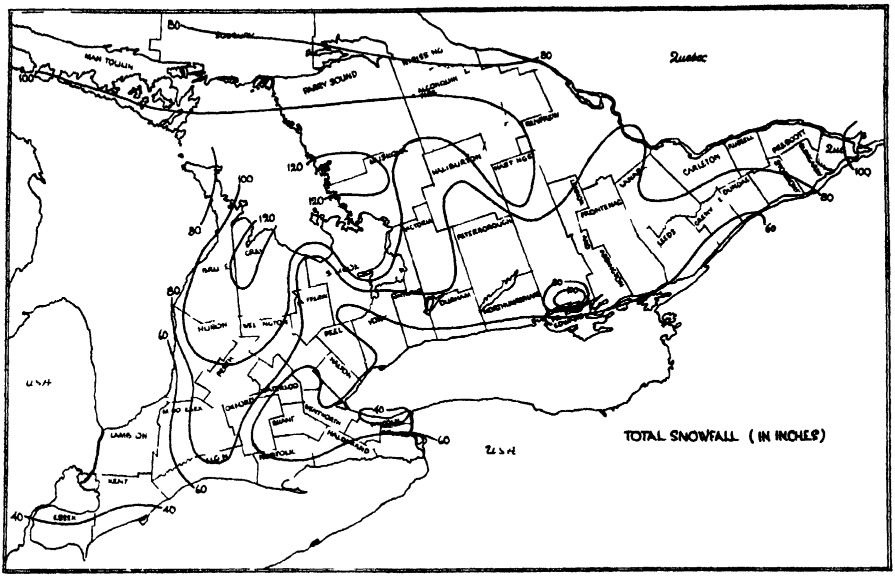

FIGURE 31. Mean annual snowfall in Southern Ontario.

In the more southerly areas the snow does not remain long on the ground but in the north and east a snow blanket of from one and one-half to two feet in depth is common during the mid-winter.

Summer Rainfall

Summer rainfall may be considered in two ways, either as the total for the growing season, or as the amount falling in the three summer months of June, July and August. In Figure 32 an approximation of the former is obtained by considering the total amounts of the period from April 1 to September 30, while the latter is shown in Figure 33. They offer further evidence that Prince Edward county and Manitoulin Island are the driest sections, and that the Leamington area, that part of Simcoe county just south of the Georgian Bay, and the district about Renfrew are relatively dry. The upland areas and the extreme east are the most favoured in this regard.

Precipitation Effectiveness

Apart from the important influence of soil type, the amount of water available to plants is a function of evaporation as well as precipitation. Since evaporation is largely conditioned by temperature there have been a number of methods evolved for correlating the two factors and thus determining the relative effectiveness of precipitation where evaporation figures are not available. One of the best is that of Thornthwaite (12) who established a relationship between precipitation and temperature corre-

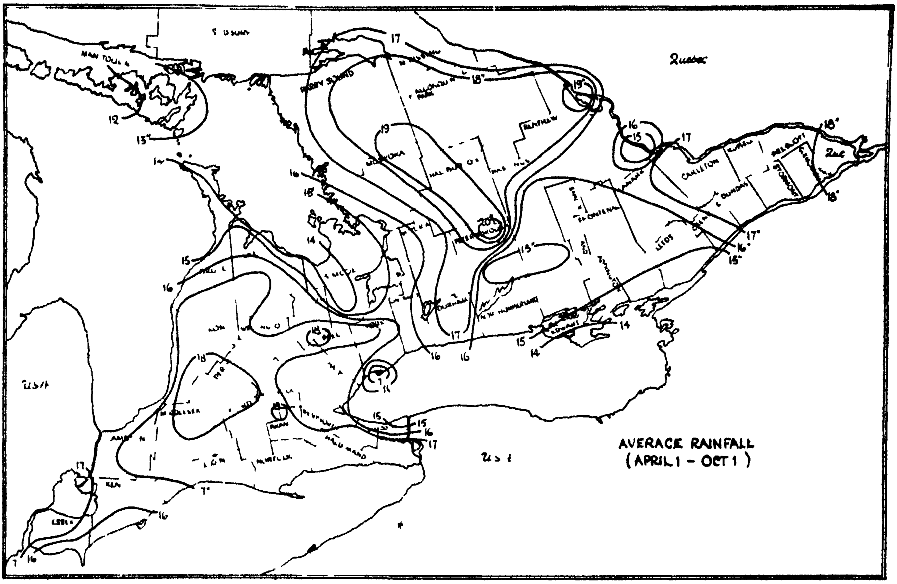

FIGURE 32. Average rainfall for the months April to September, inclusive, in Southern Ontario.

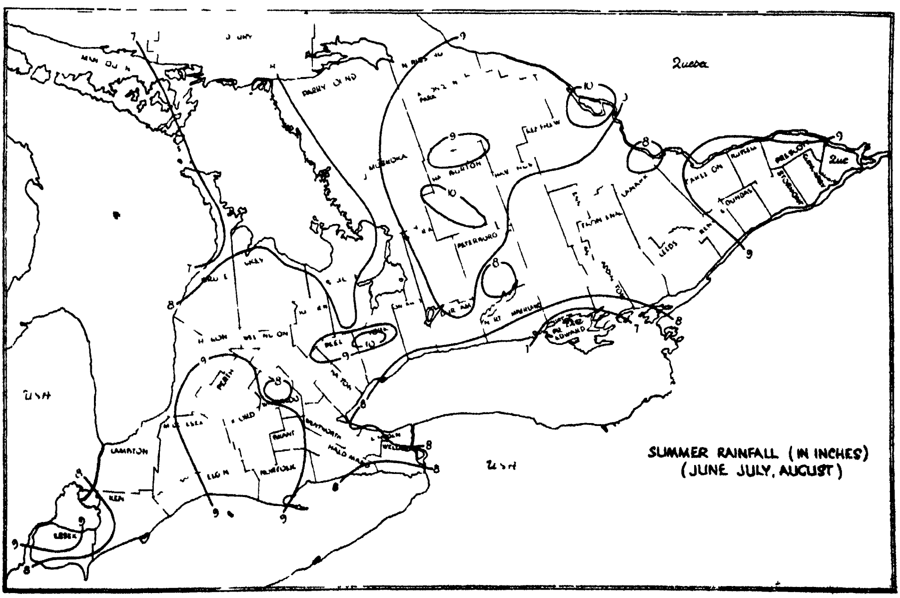

FIGURE 33. Average rainfall during the three summer months in Southern Ontario.

sponding to the ratio between precipitation and evaporation according to the data from a large number of stations in the United States. There is reason for believing that it needs to be modified to suit Ontario conditions; nevertheless, lacking systematic evaporation data, the Thornthwaite P-E index may be quite useful as an indication of relative effective precipitation. Accordingly, the results for the months of June, July and August have been calculated and are shown in Figure 34.

It will be noted that Prince Edward county and Manitoulin Island stand out as the dry areas, closely followed by Leamington, the Niagara Fruit Belt and Renfrew.

The Number of Rainy Days

In connection with precipitation, it is also useful to have a knowledge of the frequency of rains falling in any region. The observers record the number of days receiving 0.01 inch or more of precipitation, and the average number of such rainy days per year occurring in the various parts of the province is shown in Figure 35.

The rainiest spot in the province, apparently, is at Barrie where there are 188 rainy days a year. However, the much lower numbers recorded at the neighbouring stations indicate that this is a local condition rather than one which applies to any large area. Quite a large tract of country on the western slopes in Bruce and Grey counties receive between 150 and 170 days of rain or snow annually and Haliburton and Montreal record over 150 days also. The fewest rains are experienced on Pelee Island where there are less than 75; and Manitoulin, the Harrow-Leamington-Chatham section, the Niagara Fruit Belt, and Prince Edward county are also less favoured in this regard.

Drought Frequency

While the frequency of rains is important, the possibility of lengthy intervals between rains is also very significant in evaluating the agricultural capabilities of a climate. As to what interval or what amount of precipitation should constitute a "drought", there is no agreement, but it is generally felt that 1.0 inch or less of rain has a distinctly detrimental effect. The one-inch limit was therefore arbitrarily adopted, the records were examined, and the total number of times that the rainfall of the months May, June, July, August and September fell within this limit were counted. The short-time records were then weighted by the long-time ones and a fifty-year total was computed for each station. From these data the chart in Figure 36 was prepared.

It will be seen that droughts most often occur in the Leamington district, the Niagara Fruit Belt, Prince Edward county, Manitoulin, North Bruce and the south shore of Georgian Bay. The fewest droughts occur in the eastern counties, followed closely by the Muskoka and Parry Sound districts. It is particularly interesting to note that the western uplands are much more subject to droughts than the above two areas although they have about the same total precipitation. This is undoubtedly due to their relative positions in relation to the storm paths.

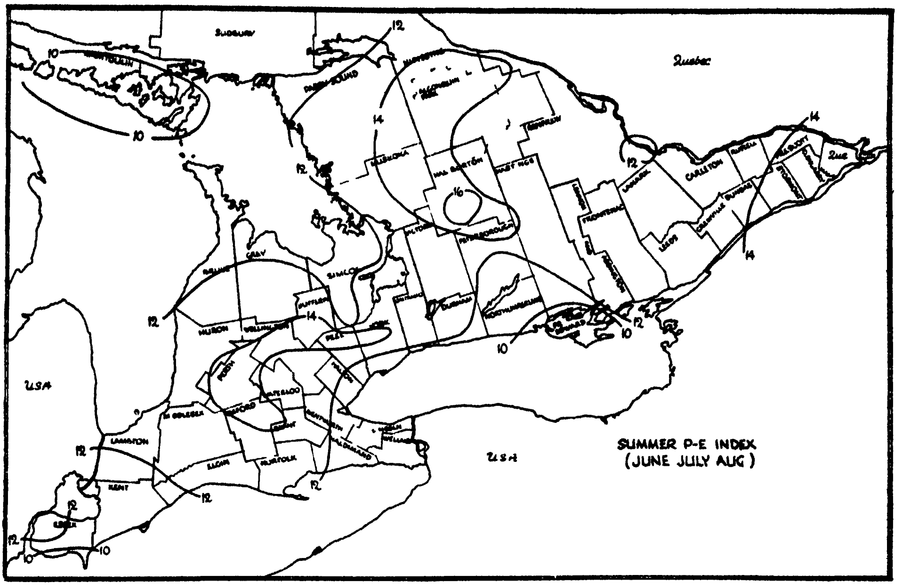

FIGURE 34 Thornthwaite P-E index for the three summer months in Southern Ontario.

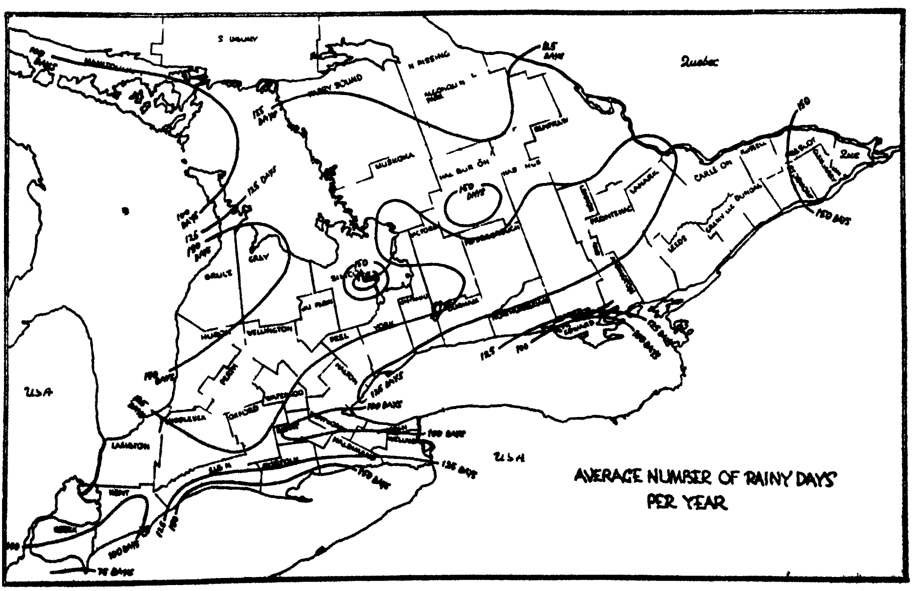

FIGURE 35. The mean annual number of days having 0 01 inch or more of precipitation.

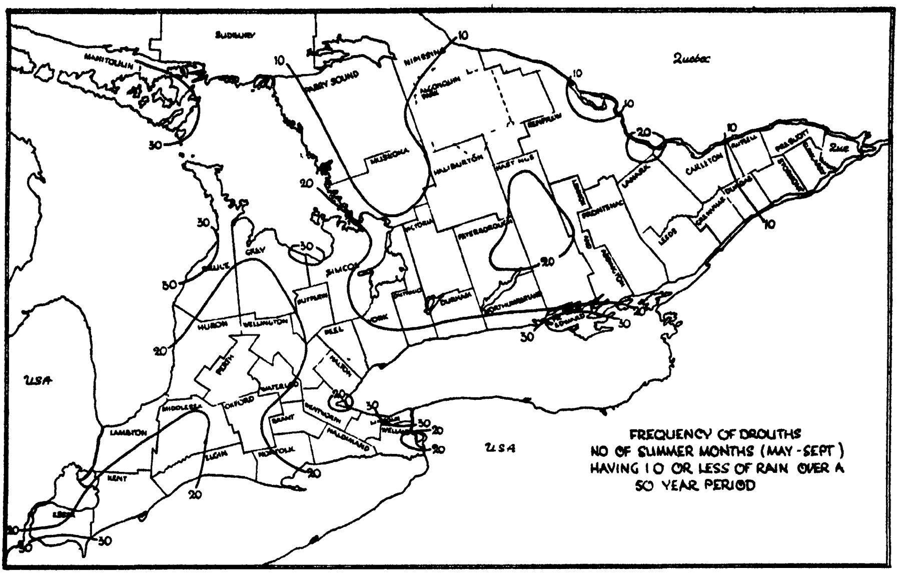

FIGURE 36. The frequency of droughts during the months of May, June, July, August and September over a fifty-year period.

Humidity

Relative humidity is calculated from wet and dry bulb readings taken three times a day as a rule. It is lowest in the middle of the day. The average relative humidity is very high during the winter months and lower during the summer. Relative humidity is probably not a limiting factor in Southern Ontario for most crops; neither is there a sufficiently consistent difference in any section to justify regional divisions on this basis. The average annual relative humidity at 8 a.m. over the province is about 80–85%.

Thunderstorms and Hailstorms

Although hail often accompanies thunderstorms, it does not follow that the places with most thunderstorms have the most hail. In the warmer sections hailstorms are less frequent than in the cooler parts; Port Stanley, with 478 thunderstorms in a 15-year period, had only 3; hailstorms; on the other hand, Ottawa, with 161 thunderstorms, had hail 27 times. Table I showing thunderstorms and hailstorms at five stations from 1895 to 1909 will illustrate the distribution of these phenomena.

TABLE 1.—THUNDERSTORMS AND HAILSTORMS IN THE 15-YEAR PERIOD FROM 1895–1909

Station	No. of thunderstorms	No. of hailstorms
Montreal	233	35
Ottawa	161	27
Southampton	181	18
London	356	10
Port Stanley	478	3

Cloudiness and Bright Sunshine

Next to temperature and precipitation, the amount of sunshine during the growing period of a crop has probably more effect on its yield than any other factor. The relative amounts of cloudiness and bright sunshine are naturally very much interrelated; however, the statistics for cloudiness are collected over a 24-hour period while sunshine is only possible during the daytime. There is no marked regional differential in either of the above characteristics. The average annual cloudiness varies from 35% to 65%, the greater part of the area having between 55% and 60% as shown in Figure 37.

Bright sunshine is recorded at only a few stations in Ontario. The annual amount received varies from 36% to 45% of the possible, with most of the area having from 43% to 45%. During the growing season there is a considerably higher percentage, ranging from 44% to 55% (see Figure 38). The northwest and northern parts of the mainland have the least, ranging from 44% to 49%; the southwest, the Niagara Fruit Belt and the north shore of Lake Ontario have from 54% to 55% and Eastern Ontario from 50% to 52% of the possible bright sunshine.

Wind

It has been previously noted that Ontario lies in the region of prevailing westerly winds, hence it is to be expected that a large proportion of the winds will come from that quadrant. However, since it also lies near the path of the majority of the cyclonic storms, the winds are very variable and may come from all directions. The "wind roses" in Figure 39 give the proportion of winds coming from the different directions according to the observations at the various stations. It will be seen that in almost all cases the prevailing direction is west, southwest or northwest, in many stations the proportions being almost equal.

Locally, topography is a factor governing the direction of winds. At Coldwater, for instance, which is situated in a valley opening out to Georgian Bay, most of the winds are either northwest or southeast, the west winds being cut off by a hill over two hundred feet in height. Along the lake shores, both on-shore and off-shore winds increase the proportion of winds in directions at right angles to the shore line.

The average annual velocity of wind is from 7 to 10 miles per hour at most stations. It is usual, however, to experience a number of gales each year in which the average maximum velocity is about 45 miles per hour. Winds of over 70 miles per hour have been recorded. Along the shore of Lake Erie most gales are registered from the southwest while along Lake Huron they come from the northwest and in Eastern Ontario the majority come from the west.

Tornadoes

Violent tornadoes of great destructive power such as occur in the Mississippi basin do not occur in Ontario. Almost every year, however, some section of the province is visited by small "twisters" which do damage to trees, fences, and buildings with a small area. A notable example of this type of storm is the one which damaged the partially constructed airport buildings at Trenton in the autumn of 1936.

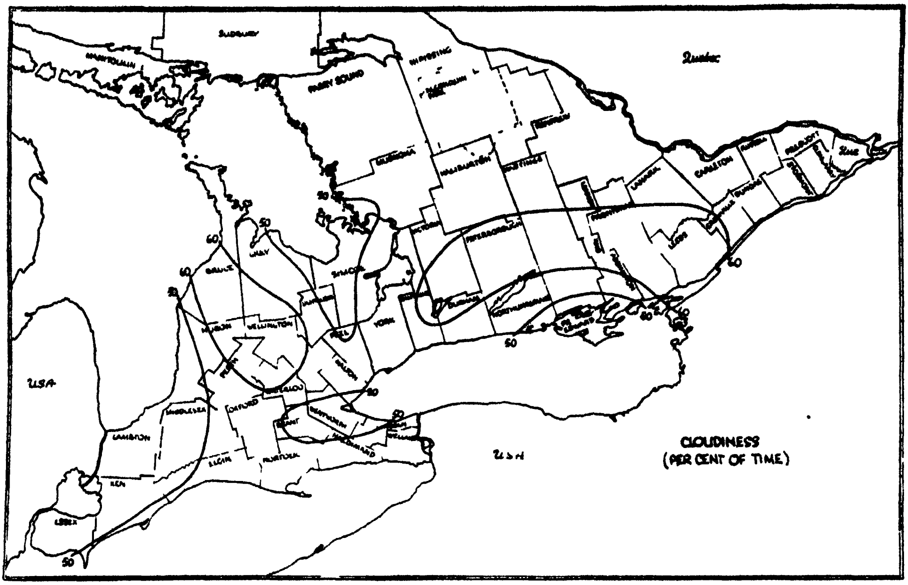

FIGURE 37. Mean annual cloudiness in Southern Ontario.

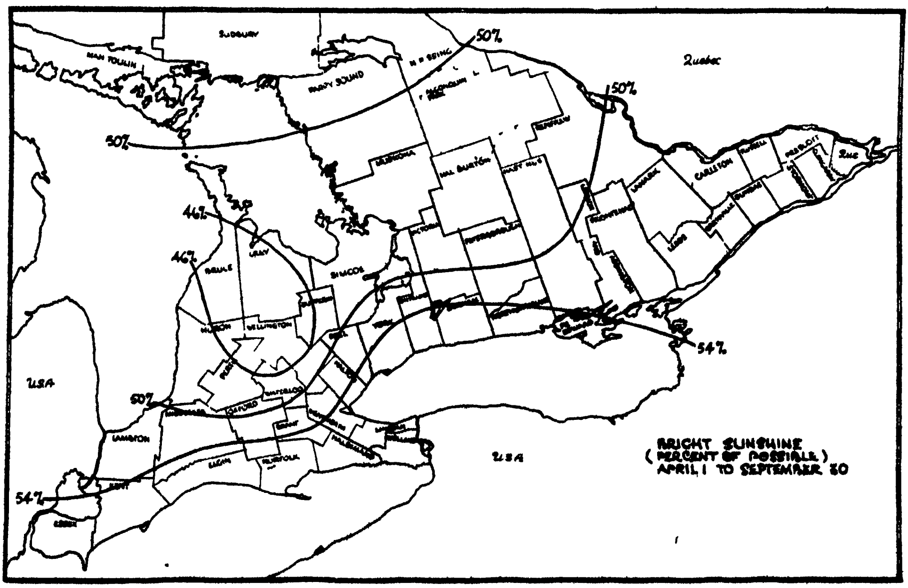

FIGURE 38. Average percentage of possible bright sunshine received during the growing season in Southern Ontario.

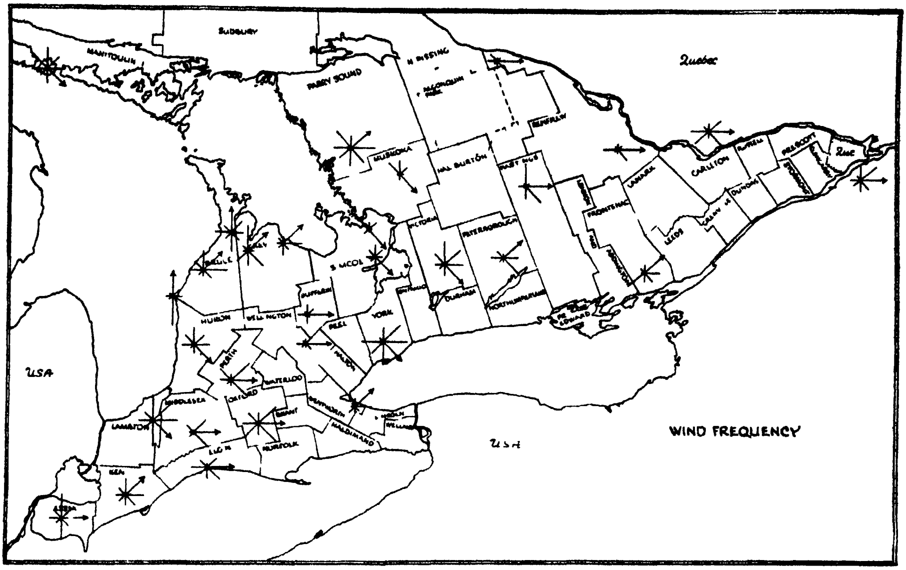

FIGURE 39. Relative frequency of winds from different directions in Southern Ontario. (Reading from the centre, outward.)

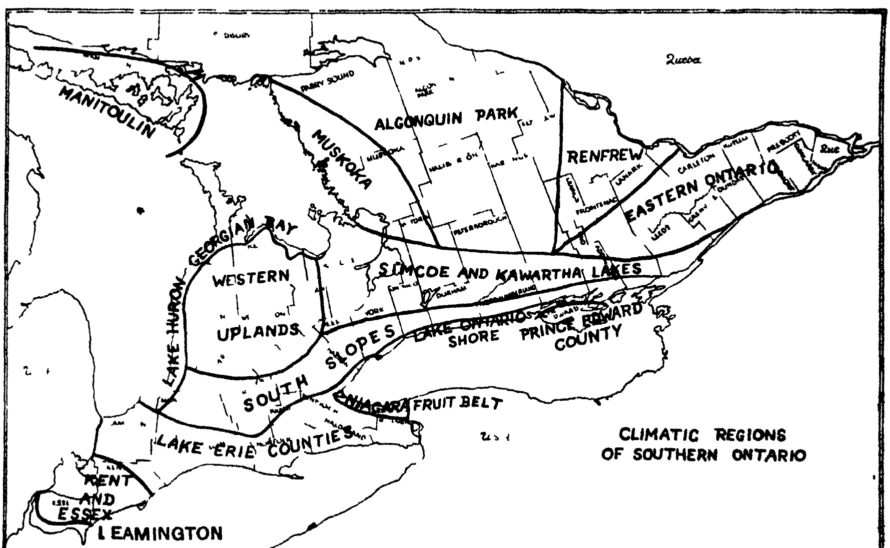

FIGURE 40. Climatic Regions of Southern Ontario.

III. REGIONAL CLIMATES OF SOUTHERN ONTARIO

On the basis of the foregoing discussion and isopleth maps, the southern part of the Province of Ontario has been divided into fifteen climatic regions, the outlines of which are shown in Figure 40. These areas may, to a certain extent, be regarded as crop regions, since their boundaries have a tendency to coincide with the known distribution of some of the more important crops. In the main, it is the coincidence of isothermal, isohyethal and isochronal lines which determine the location of the boundaries of each region. In the following paragraphs a description of each regional climate will be given, beginning with those having the earliest, warmest and longest seasons, and following in order with those less favoured.

1. The Leamington Area

A small area along the shore of Lake Erie in Essex county is notably the warmest and earliest spot in the province and has for years been noted for the excellence and variety of tender crops grown there. The annual mean of 48° F., winter mean of 26°, spring mean of 45°, summer mean of 69° to 70°, and fall mean of 51° are all the warmest temperatures in the province. The tempering influence of the lake is seen especially in the winter when the lowest recorded temperature of −20° is exceeded considerably in contiguous areas a few miles inland. The extreme high for the area is 105°, giving an extreme temperature range of 125°.

The growing season begins nearly a week earlier than that of any other area, usually during the first week in April. This is an advantage to such crops as asparagus, strawberries, early potatoes and early corn. The average length of the growing season is about 216 days. The influence of the lake and the resultant narrow daily range of temperature make this area the most free of frost of any in Ontario. The average frost-free period of 165 to 169 days is of special importance to such crops as tomatoes, tobacco, and corn.

The area suffers somewhat from lack of moisture. As a region it has the lowest annual precipitation, only 28.1 inches; its average snowfall is only 32 inches; while three years out of five are apt to have drought periods. Because of the prevailing high summer temperatures, the effectiveness of the precipitation is very low even though slightly more than half of it falls during the growing season.

On Peleé Island the conditions are quite similar but there is a slightly longer frost-free period.

2. The Niagara Fruit Belt

The Niagara Fruit Belt is also a small region, consisting of a narrow strip between the southern shore of Lake Ontario and the Niagara Escarpment. The mean annual temperature is 46° to 47°, winter mean 25°, spring mean 43°, summer mean 68° and autumn mean 51°, values which are for the most part from ½° to 1° higher than those of the adjoining area to the south above the escarpment. In the matter of extreme low temperatures, this area is most fortunate, −12° to −16° having been infrequently recorded. This is of importance in the growing of peaches and other tender perennial crops. The highest temperature on record is 104°, giving an extreme temperature range of 120°. The growing season has an average length of 212 days, from April 10–12 to November 7–9.

An average frost-free period of 158 days may be expected. This region is a little cooler and later in the spring than the Leamington area but has an autumn season equally favorable.

This is also one of the drier parts of the province. The annual precipitation is about 30 inches, the average snowfall is also low, an average of 38″ being recorded. High summer temperatures result in a precipitation effectiveness almost as low as that of Leamington, and drought periods are almost as frequent.

There is a slight range of conditions in different parts of the area; the western end has more extreme temperatures and receives somewhat more precipitation than the eastern end.

3. The Counties of Kent and Essex

The counties of Kent and Essex constitute a region of low relief lying between Lake St. Clair and Lake Erie. It ranges in altitude from 600′ to 700′, but the greater part of it is almost flat so that there are no topographic barriers to climatic uniformity.

The mean annual temperature is 47°, one degree lower than that of the Leamington area, and one degree higher than that of the region immediately to the north. The seasonal temperatures are similar to those of the Niagara Fruit Belt with the exception that the spring is about ½° warmer, and the fall is ½° cooler. The extreme high temperature of 106° was recorded at Chatham in July, 1936. The extreme low is −27°, giving a range of 133°. This, together with the prevailing heavy clay soils, accounts for the lack of tender fruits in most of the region. The northern boundary closely approximates the July isotherm of 70° which is generally recognized as the limit of successful seed corn and sugar beet culture. The growing season with mean temperatures above 42° extends from the first or second week in April to the first week in November with a length of from 203 to 213 days. The last killing frost in the spring may be expected before May 10, while the first fall frost usually holds off until after October 10, giving an average frost-free period of about 155 days.

The average precipitation at the different stations varies from 28 to 32 inches per annum; snowfall is light, averaging about 40 inches. The summer precipitation is slightly greater than that of the winter, and about 8.5 inches falls in the months of June, July and August. The precipitation effectiveness index of 12 0 for the summer months is below the average for the province, and the frequency of summer droughts is about 20, being the highest at Chatham where it is 27.

4. Lake Erie Counties

This region, bounded by Lake Erie on the south, Lake Ontario to the east and Lake Huron to the west, has a climate modified by the influence of these lakes as shown by the mean daily range of temperature, frost dates, and length of growing season. Although having a warm, early season it is not quite so well favored as the three regions previously outlined. It is an area of gentle relief, varying in elevation from about 600′ to slightly over 800′, the most prominent features being the crests of some of the glacial moraines.

Except in the Niagara Peninsula, the northern boundary is formed by the annual isotherm of 45°. Winter temperature ranges from 23° to 24°,

Spring temperatures are about 43°, with 42° along the northern border and also along the shore of Lake Erie. Summer temperatures average about 67° with 66° along Lake Erie. Fall temperatures vary from 48° to 50°, being warmer along the lake shores. The extreme low temperatures range from −21° to −35° and the highest temperature ever recorded is 106. The frost-free period varies from 160 to 135 days, depending on the distance from the lakes. On the other hand the growing season has a fairly uniform length of about 200 days from the middle of April to the first week in November.

The average precipitation is 33.8 inches, but is heavier in Norfolk, Elgin and Middlesex and lighter both to the east and west. The normal snowfall varies from 40 to 90 inches in the same manner. The growing season receives slightly over half the precipitation. The P-E index for the three summer months ranges from 10.5 to 13.5. The drought frequency is about 20, strangely enough, being higher in the areas receiving greater precipitation. The greater rainfall in the central part of the region is not apparent because of the sandy soils.

5. Lake Ontario Shore

The ameliorating influence of Lake Ontario seems to extend inland a much shorter distance than that of Lake Erie. To a certain extent this is emphasized by topography since Lake Ontario is bordered by the well marked plain of ancient Lake Iroquois behind which the land rises sharply. The altitude of this lake plain is from 250 feet to 400 feet.

The mean annual temperature of this strip is 44°, which is 1° warmer than the area immediately to the north. The mean seasonal temperatures are: winter 21°, spring 41°, summer 66°, fall 48°. These figures offer little in the way of distinction from the adjoining region, but in the matter of extremes of temperature, daily range of temperature and frost-free periods, the influence of the lake is clearly to be seen. The highest recorded temperature is 104° at Toronto; the lowest ranges from −27° to −30°, an extreme range of 134° which is about equivalent to that of Kent and Essex. The mean daily range of 17°–19° is also the same as that of southwestern Ontario. The average date of the last frost in the spring varies from May 8 to 15, while that of the first frost in the fall is from October 2 to 13, giving an average frost-free period of 141 to 158 days. The growing season begins at the same time as that of the Lake Erie region but closes before the end of October with an average length of about 197 days.

The mean annual precipitation varies from 30.0 to 33.5 inches, and there is a moderate snowfall of 65 to 66 inches. The rainfall for the growing season is slightly more than half the total (15.5 inches to 17.3 inches), while that of June, July and August ranges from 7 to 8.5 inches. Drought frequency is fairly high, averaging about 25, while the summer P-E index of 11.0 is fairly low.

6. Prince Edward County

This area occupies a unique position, jutting out into Lake Ontario and having many re-entrant bays so that no part of it is far from the water. Physiographically a flat limestone plateau, most of it has an altitude of

about 400 feet above sea level, which is 150 feet above the lake level. There are, however, some bordering areas which lie between it and the surface of Lake Ontario.

The annual mean temperature is 44°, the winter mean 20°, spring 41°, summer 67°, and fall 48°. With the exception of a slightly hotter summer, these temperatures are the same as those of the Lake Ontario shore. The mean daily range (17° to 19°), frost dates, and growing season are also similar.

The chief reason for describing this area separately is to be found in the moisture relationships. The average annual precipitation is only 28.6 inches, and the depth of snowfall is 55 inches. Only 13.9 inches, or somewhat less than half the total falls between April 1 and October 1, while 6.8 inches is the average for June, July and August. This, in combination with a high summer temperature (July mean of 70°), gives a precipitation effectiveness index of only 9 5, the lowest in Ontario. The drought frequency of 34 is, also, one of the highest. This tendency to drought is intensified by the fact that much of the soil in the county is extremely shallow and has little water-holding capacity. In the areas of good soil, however, a great variety of canning crops, fruits and even seed corn can be grown.

7. *Lake Huron-Georgian Bay*

Along the shores of Lake Huron and Georgian Bay there is a narrow zone in which the influence of the lake is sufficiently marked to differentiate it from the adjacent hinterland. Along Georgian Bay, this strip is sharply delimited by topography, but on the Lake Huron shore the transition is more gradual. Most of the area lies below an elevation of 800 feet.

The mean annual temperature of 44° is similar to that of the Lake Ontario shore, as is also the winter temperature of 20° to 23°. The spring temperature of 39° to 41 5° is slightly lower as is also the summer temperature of 64° to 66°. On the other hand, the fall temperature of 49° is about 1° higher. The mean daily range of 15° to 17° is low and is about equivalent to that of the Leamington area. An extreme high temperature of 102° has been recorded at Collingwood but elsewhere there is no record above 100°. The extreme low records range from −27° to −35°. The average date of the last frost in the spring varies from May 7 to 17, and that of the first frost in the fall from October 6 to 13, leaving a frost-free period of 142 to 157 days, or about the equivalent of that of the Lake Erie region. The growing period is between April 16 to 23 and October 30 to November 7, varying from 189 to 200 days at various stations, Collingwood having just as long a season as the southern end of Lake Huron.

Mean annual precipitation varies from 28.4 inches at Collingwood to 36.4 inches at Owen Sound. Snowfall ranges from 60 inches at Goderich to 125 inches at Owen Sound. From 14 to 16 inches of rain falls between April 1 and October 1, while most of the area receives about 8 inches during June, July and August. Drought frequencies range from 15 to 30 while the index of precipitation effectiveness lies between 10.5 and 13. The west side of the Bruce Peninsula is much drier than the rest of the area and has a climate that in some respects resembles that of Manitoulin.

It has been previously stated that climatic regions are to a certain extent crop regions, and nowhere is this more plainly shown than in the three just described. The outstanding crop in these areas is the apple, the greater part of the commercial production of the province originating therein.

The factors which limit the successful culture of apples are early and late frosts, winter temperatures, especially extremes, summer temperatures and precipitation, and the amount of sunshine. The proximity to large water surfaces is the chief cause of the climatic modification which makes these regions outstanding in apple production. The daily range of temperature is kept within narrow limits throughout the year, with a consequent lessening of frost hazard. Spring temperatures are kept low at first, thus retarding the bloom beyond the frost date, and on-shore breezes moderate the summer temperatures, lessening the danger from scald and drought. The slow cooling of the water causes a long open fall season, permitting the colouring of the fruit and allowing the tree sufficient time to harden off the new wood in preparation for the winter.

Protection from wind is also important. This is especially exemplified in the Lake Huron and Georgian Bay region. The Blue Mountain skirts the shore of Georgian Bay, affording protection from gales, and this is one of the reasons why areas such as the Beaver Valley are better suited to apple growing than is the Lake Huron shore.

8. The South Slopes

To the north of the Lake Erie region and the Lake Ontario shore there is a belt of country with a southern exposure, in which the climate is somewhat milder than that of the regions to the north, but which does not enjoy the modification of the lake influence to the extent of the first-mentioned areas. In altitude, most of the area ranges from 500 to 1000 feet above sea level.

The mean annual temperature ranges from 43° to 45°. The winter isotherms of 18° and 19° approximate the northern boundary and in some parts 23° is reached. The spring mean ranges from 41° to 42° at most stations and is similar to that of the Lake Ontario shore; the summer mean of 66° is also similar. The fall temperature mean of 47° is intermediate between that of the lake regions and that of the Western uplands. The temperature extremes at the various stations are: low, −27° to −39°; high, 101° to 105°; the greatest range at any one station being 143°. The mean daily range of 19° is wider than that of the shore regions but similar to much of the territory to the north. The average length of the frost-free period ranges from 133 to 147 days, from May 11 to 20 until September 28 or in some places October 3. This is from one to two weeks longer than the central part of the uplands and certain parts of Simcoe county. The growing season of 192 to 200 days is similar to that of the Lake Erie and Lake Ontario regions but definitely longer than that of the regions to the north.

Annual precipitation varies from 32 to 38 inches, with a little less than half falling between April 1 and September 30, and from 7.0 to 9.6 inches in June, July and August. Snowfall varies from 50 to 90 inches.

9. Simcoe and Kawartha Lakes

The area east of the Niagara escarpment, lying between the interlobate moraine and the boundary of the Precambrian, together with an eastern extension in which climatic data are similar, has been separated from the adjoining area to the south for a number of reasons, the chief of which is a definitely colder winter and more backward spring. The bulk of the area has an elevation of about 800 feet above sea level but reaches 1200 feet in some places.

The mean annual temperature is 42° to 44°. Winter temperatures range from 17° to 19°, spring 39° to 41°, summer 65° to 67°, fall 46° to 47°. The western uplands have similar winter temperatures but are cooler in spring and summer. On the other hand, eastern Ontario has more severe winters. The lowest temperature ever recorded in this region is −42°; the highest is 104°, giving an extreme range of 146°.

The frost-free period ranges from 120 to 140 days on the average, while the growing season of 188 to 195 days is about five days shorter than that of the south slopes.

The precipitation of this region is somewhat lighter than that of those around it, chiefly because a large part of the area lies in the "rain-shadow" created by the western uplands. Annual averages range from 26.5 to 33 9 inches. The growing season receives slightly more than half the total with from 7.0 to 9.0 inches falling in the months of June, July and August. The average index of precipitation effectiveness is 12.0; the frequency of droughts ranges from 15 to 25 which is similar to that of the adjoining areas to the south but markedly greater than in the regions to the north and east. The normal snowfall of 55 to 106 inches resembles that of nearby areas.

10. Eastern Ontario

The extreme easterly portion of the province is an area of low elevations and gentle relief, the largest part of which is drained by the Ottawa River and its tributaries. It is in many ways climatically akin to the Middle Saint Lawrence Region in Quebec.

The mean annual temperature varies from 41° to 43°. There is a wide range in the winter mean from 13.5° to 17°. January and February are equally cold at most stations. Winter temperatures divide this area from the rest of the Ontario lowlands and place its climate in the group with those of the higher and more northerly portions. It is notable that little winter wheat is grown, the winter isotherm of 18° corresponding to the coldward limit of most of the commonly cultivated varieties. Spring temperatures of 40.7° to 41.7° are slightly in advance of those in the adjacent regions to the west, while the summer average of 66° is common to most of the regions adjoining Lakes Ontario, Huron and Erie. The fall mean of 45° to 47° resembles those of the Simcoe and Kawartha Lakes and the western uplands. The extreme high temperature record stands at 104° while the extreme low is −40° giving a range of 144°. The mean daily range of temperature is not excessive, being 19° to 20° over most of the area. This is reflected in the frost-free period of 130 to 140 days, the average date of the last frost in the spring varying from May 11 to 24,

while that of the first fall frost occurs between September 24 and October 1 at most stations. The average length of the growing season is 191 to 197 days.

Precipitation varies widely in this region; the agriculturally important areas receive from 30 to 40 inches; increasing rapidly toward the east where a belt of heavy precipitation is located in the middle St. Lawrence Region. Snowfall also varies, with most of the area receiving from 72 to 96 inches annually. Summer rainfall shows less variation, from 16 to 18 inches falling from April 1 to September 30, while about 9 inches falls in the three summer months. Drought frequencies are low, averaging about 10, and the index of effective precipitation for June, July and August is from 12.5 to 14.5.

On the whole, eastern Ontario has a climate of temperature extremes, with very cold snowy winters and warm summers with adequate rainfall and little likelihood of drought. It is unsuitable for the production of winter wheat, fruits or tender crops.

11. The Western Uplands

The most elevated part of Southern Ontario, ranging from 1000 to over 1700 feet, comprises parts of Wellington, Waterloo, Perth, Huron, Bruce, Grey and Dufferin counties. On the north and east it presents faces of sharp relief, but slopes gradually into the adjoining regions on the south and west. Climatically it is not homogeneous, for at some seasons of the year the outlying portions differ less from the adjoining regions than they do from the central and more elevated parts.

The mean annual temperature ranges from 41° to 44° and is equivalent to that of the Kawartha Lakes or Eastern Ontario. The winter temperatures of 18° to 21° are, in the main, equivalent to those of the Kawartha region but spring temperatures of 37° to 40° are definitely cooler. Summer temperatures of 64° to 65° are about 1° below those of adjoining areas except in the case of the Lake Huron shore which is cooled by westerly breezes. Fall temperatures vary from 45.5° to 48°. The region has an extreme temperature range of 145°, from −43° to 102°. The mean daily range for the year is 19° to 21° with as much as 26° in July. The frost-free season of 125 to 140 days is much the same as that of Eastern Ontario, being nearly a month shorter than in the milder parts of the adjoining shore regions. The growing season varies from 180 to 195 days, being shortest in the most elevated part of the region.

The western side of the region has a heavy precipitation, 38 inches annually, decreasing eastwardly to about 32 inches. It is interesting to note that it is not the most elevated area that receives the most rain, but rather, that part having a westerly slope. Snowfall varies from 80 to 125 inches, being heaviest northward. The area of high summer rainfall lies on the southern border of the uplands, receiving from 16 to 18 inches between April 1 and September 30, or about the same as eastern Ontario. Between 8 and 9 inches of rain is received in the months of June, July and August. The uplands are less subject to drought than most of the adjoining areas, having an average frequency of about 18, which, however, is considerably greater than that of eastern Ontario or Muskoka, both of which

have about the same amount of precipitation. The P-E index for the three summer months is 12.0 to 14.5, indicating that this is to be regarded as a moderately humid region.

12. Muskoka

Along the eastern shore of Georgian Bay in the districts of Muskoka and Parry Sound, there is a region of moderate relief in which the modifying influence of the lake is manifest. The altitude varies from about 600 feet to over 900 feet above sea level at the border of the highlands of Algonquin Park.

The mean annual temperature is 40° to 42°. Winter temperatures vary from 14° to 17°, the spring mean is 37° to 39°, summer 63° to 65°, and autumn 43° to 46°. These temperatures are several degrees higher than those of the Algonquin Park but, particularly the spring and summer means, are somewhat lower than those of Renfrew. The extreme range of temperature at any one station is 146°, from −48° to 98°. The mean daily range of temperature is 20° to 21°, somewhat less than that of Algonquin Park. The frost-free period varies from 117 to 137 days, and the growing period from 177 to 189 days.

The western slope, facing Georgian Bay, gives this region a heavy precipitation. At Beatrice the annual average is 40 inches and most of the region receives about 38 inches annually. Snowfall is also heavy with averages as high as 130 inches annually being recorded. Somewhat less than half the rainfall is received in the growing season, and about 9 inches is the average for the months of June, July and August. The P-E index is high, 12.5 to 15 for the summer months, and drought frequency is low with an average of 10. It is interesting to note that according to the classification of Thornthwaite (12), this region has a climate similar to that of the Maritime Provinces.

13. Renfrew

The Renfrew region consists chiefly of that portion of the Ottawa valley lying in the county of Renfrew, together with some of the immediately adjacent townships. It is a comparatively narrow depression with altitudes ranging from 400 to 800 feet above sea level, and flanked by the rough highlands of the Laurentian shield. The proximity of these highlands has a distinct influence on the climate.

The mean annual temperature varies from 39° to 41°. Winters are cold, with an average temperature of 13°. Spring with average temperatures of 39° to 40° is slightly ahead of that of Muskoka; summers also are warmer, ranging from 64° to 66°. The mean fall temperature is 44° to 45°. The extremes of temperature cover a range of 143° from −40° to 103°. The tendency to extremes is shown also in the mean daily range of 22° with as much as 26° in July. In most of the region the last spring frost usually occurs between May 24 and June 1, and the first fall frost about September 20. Frost, however, is a real hazard, and only the month of July can be said to be frost-free since frosts have been recorded in all other months. The growing season lasts from April 16 or 20 until October 21 or 25, with a length of 185 to 190 days.

Although this is a small area, the range of precipitation is great, from 26.3 to 35.7 inches annually, the region in the vicinity of Renfrew being much drier than that adjoining Pembroke. Renfrew also has less snowfall, only 68 inches as compared with more than 80 inches both to the north and to the south. The same holds true of summer rainfall, the average precipitation from April 1 to September 30 varying from 14.5 to 19.4 inches, while for June, July and August there is a range of 7.6 to 10.0 inches. The P-E index for the summer months varies from 11.0 to 13.5, while drought frequency varies from 22 at Renfrew to 8 at Pembroke.

In contrast to the almost maritime climate of Muskoka, this is typically a cool inland region with moderate rainfall, suitable for general farming with hardy varieties but it cannot be considered safe for any of the special crops which require a much less extreme type of climate.

14. Manitoulin

Manitoulin consists of a large island and a number of smaller ones lying in the northern part of Lake Huron. In general it varies in altitude from 600 to 800 feet above sea level, with some hills above 1000 feet. It has been here included with the regions of Southern Ontario because the modifying influence of the lake has created a climate more nearly akin to that of the other shore regions than it is to that of Northern Ontario. The contrasting relationships can be seen clearly on many of the isothermal maps, but especially upon those of the fall and winter. It will be noted also that there is a difference between the north and south sides of the island.

The mean annual temperature is 40°. Winter temperatures vary from 16° on the north to 19° on the south; spring temperatures of 36.7° obtain at both stations; summer is slightly cooler on the south sides, 61.3° as compared with 62.3°; autumn temperatures vary in the same way from 45° to 46°.

The extreme high temperature records are 97° and 100°, also showing the influence of the lake. The lowest temperature on record is −41°, giving an extreme range of 141° which is rather wide for a region surrounded by water. The mean daily range of temperature is 19° to 20° over the year, with 23° to 24° in midsummer. The frost-free period averages 125 to 129 days, from about May 26 to the end of September; however, frosts have been recorded in all months. The growing season opens April 24 to 26 and closes October 21 to 25, the average length being 178 to 186 days.

This is a region of light precipitation, the annual average being 27.8 to 30.0 inches. Snowfall ranges from 83 to 118 inches. Much less than half the total precipitation falls in the growing season, the averages from April 1 to September 30 being 11.6 to 12.9 inches, with 6.1 to 6.5 inches for the three summer months. Drought frequency is high, 32 to 33, while the P-E index for the summer months is only 9.0 to 9.5.

The climate of Manitoulin is one of moderately cold, snowy winters, late springs, cool, dry and sunny summers, and open falls. In degree of drought it is in great contrast to that of Muskoka, which it otherwise resembles.

15. Algonquin Park

In addition to the Algonquin Park itself a very large area of the adjoining Precambrian upland is included in this region. There is considerable variation in the data but because of the lack of soil covering on the rock it is not considered to be of enough importance agriculturally to warrant further subdivision at this time. It is an elevated area, practically all above 1000 feet and reaching 1500 feet above sea level in some places.

The central part has a mean annual temperature of 38°, the lowest in Southern Ontario, and 10° below that of Leamington. Winter temperatures of 11° to 15°, spring temperatures of 37° to 39°, summer temperatures of 62° to 65° and fall temperatures of 42° to 44° stamp this region as the coldest and latest in the southern part of the province while with an average frost-free period of 78 to 120 days and the possibility of killing frosts in any month it is, for most crops, climatically the least favoured. The lowest temperature on record is −50° at Madawaska, while the highest temperature record is 103° at Apsley; the extreme range at any one station is 151°, the widest found in the area under consideration.

The average annual precipitation for the region is 35.0 inches of which somewhat more than one-half falls between April 1 and September 30. Snowfall is heavy with an average of 90 inches. The P-E index for the summer months is 14.0, the highest average for any of the fifteen regions, but the drought frequency averages 18 which is higher than that of several other regions.

SUMMARY

While the climate of Southern Ontario is usually stated to be of the modified humid continental type, actually the region is a borderland in which a number of different types of climate merge. It has been the purpose of this paper to analyze and describe these types in sufficient detail and in such a way as to be an aid in making correlations with crop growth.

In order to understand clearly the underlying causes of the great variation in climate, the major climatic controls have been dealt with at some length. It is of special importance to note that the area lies in the path of the most frequent occurrence of cyclonic storms, and that its position with respect to the Great Lakes greatly modifies both temperature and moisture relationships. The position of upland areas lying across the direction of the prevailing winds and thus causing belts of high and low precipitation is also quite significant.

In order to facilitate the discussion a series of isopleth maps have been constructed. It is shown, for instance, that mean annual temperatures vary 10° over the area, mean seasonal temperatures from 7° to 15°, and the average frost-free period shows a difference of almost 100 days from the longest to the shortest. Mean annual precipitation shows an extreme range from 26 to 40 inches, and other moisture factors vary accordingly.

The bulk of the information has been obtained directly from the averages of the observations of the Dominion Meteorological Service but in the calculation of average frost-free period a new device has been used. By comparison of the records of long-time stations it has been shown that the mean temperature of the frost date is equivalent to 32° plus the mean daily range of temperature, and this formula has been used in arriving at

TABLE 2.—REGIONAL CLIMATES OF SOUTHERN ONTARIO

Climatic Region	Leamington	Niagara Fruit Belt	Kent and Essex	Lake Erie Counties	Lake Ontario Shore	Prince Edward County	Lake Huron — Georgian Bay	South Slopes
Altitude	600′	250′–400′	600′–700′	600′–800′	250′–400′	250′–400′	600′–800′	600′–1000′
Mean Annual Temperature	48°	47°	47°	46°	44°	44°	44°	44°
Mean Winter Temperature	26°	25°	25°	23°	21°	20°	22°	21°
Mean Spring Temperature	45°	43°	44°	43°	41°	41°	40°	41°
Mean Summer Temperature	69°	68°	68°	67°	66°	67°	64°	66°
Mean Fall Temperature	51°	51°	50°	49°	48°	48°	48°	47°
Extreme Low Temperature	−20°	−16°	−27°	−34°	−30°	−33°	−35°	−39°
Extreme High Temperature	105°	104°	106°	106°	104°	100°	102°	105°
Daily Range of Temperature	17°	17°	18°	18°	17°	18°	17°	19°
Av. Date of Last Frost in Spring	May 1	May 8	May 8	May 10	May 11	May 15	May 15	May 15
Av. Date of First Frost in Fall	Oct. 15	Oct. 13	Oct. 10	Oct. 10	Oct. 3	Oct. 5	Oct. 10	Sept. 28
Av. Length of Frost-Free Period (Days)	167	158	155	153	145	143	148	135
Beginning of Growing Season	April 5	April 11	April 11	April 14	April 15	April 16	April 19	April 15
End of Growing Season	Nov. 7	Nov. 9	Nov. 4	Nov. 3	Oct. 29	Oct. 30	Nov. 1	Oct. 28
Av. Length of Growing Season (Days)	216	212	207	203	197	197	196	196
Av. Annual Precipitation	28 1″	30.9″	29 0″	33.8″	33.0″	28.6″	32.3″	32.6″
Average Annual Snowfall	32″	38″	40″	61″	60″	55″	95″	60″
Av. Rainfall April 1–Sept. 30	15.5″	15.7″	17 0″	17.1″	16.3″	13.9″	14.6″	17.0″
Av. Summer Rainfall (J.J.A.)	7.5″	8 0″	8 5″	8 8″	8.0″	6.7″	7.7″	8.7″
P-E Index (June, July, August)	10	11 5	12 0	12 5	11.0	9.5	11.5	12.5
Frequency of Droughts	30	30	20	20	25	34	22	20
Per Cent Possible Sunshine in Growing Season	55	55	54	54	54	54	48	50

TABLE 2.—REGIONAL CLIMATES OF SOUTHERN ONTARIO

Climatic Region	Simcoe and Kawartha Lakes	Eastern Counties	Western Uplands	Muskoka	Renfrew	Manitoulin	Algonquin Park
Altitude	600′–1000′	200′–400′	1000′–1800′	600′–900′	400′–800′	600′–1000′	100′–1400′
Mean Annual Temperature	43°	42°	42°	41°	40°	40°	39°
Mean Winter Temperature	18°	16°	16°	16°	13°	18°	12°
Mean Spring Temperature	40°	41°	41°	38°	39°	37°	37°
Mean Summer Temperature	65°	66°	66°	64°	65°	62°	63°
Mean Fall Temperature	46°	46°	46°	45°	44°	45°	43°
Extreme Low Temperature	−42°	−40°	−43°	−48°	−40°	−41°	−50°
Extreme High Temperature	104°	104°	102°	98°	103°	100°	103°
Daily Range of Temperature	19°	19°	19°	21°	22°	19°	23°
Av. Date of Last Frost in Spring	May 19	May 18	May 23	May 24	May 24	May 26	June 10
Av. Date of First Frost in Fall	Sept. 26	Sept. 26	Sept. 26	Sept. 24	Sept. 20	Sept. 30	Sept. 10
Av. Length of Frost-Free Period (Days)	130	131	126	123	119	127	93
Beginning of Growing Season	April 18	April 15	April 19	April 22	April 18	April 25	April 24
End of Growing Season	Oct. 25	Oct. 26	Oct. 25	Oct. 21	Oct. 23	Oct. 23	Oct. 17
Av. Length of Growing Season (Days)	191	194	189	182	188	181	176
Av. Annual Precipitation	30.4″	34.0″	36.0″	38.0″	31.0″	28.9″	35.0″
Average Annual Snowfall	76″	87″	100″	114″	80″	100″	90″
Av. Rainfall April 1–Sept. 30	15.6″	17 5″	17.5″	17.7″	16.7″	12.3″	18.2″
Av. Summer Rainfall (J.J.A.)	8.2″	9.2″	8.9″	9.1″	8.9″	6.3″	9.2″
P-E Index (June, July, August)	12.0	13.5	13 5	13.5	13.0	9.5	14.0
Frequency of Droughts	19	9	18	10	15	33	18
Per Cent Possible Sunshine in Growing Season	52	52	45	50	50	52	50

the probable frost dates of all stations. The effectiveness of precipitation during the growing season has also been indicated both by the use of Thornthwaite's P-E index and by the calculation of drought frequency.

On the basis of topography, location, and the coincidence of isopleth lines, it has been possible to divide Southern Ontario into fifteen regions, the chief climatic characteristics of which have been arranged in Table 2 in order to facilitate comparison.

It should be understood that in a study of this kind it is the normal or average characteristics that are employed, and that in making correlations between climate and crop response, the variations of the different factors must be taken into account. Nevertheless the definition of regional climates limits the field which must be covered and, in conjunction with the soil survey, will form an effective basis for all studies which aim to determine the regional adaptations of any variety of plant.

ACKNOWLEDGMENTS

The writers wish to express their thanks to Dr. H. B. Speakman and Mr. T. D. Jarvis of the Ontario Research Foundation for their interest in, and support of, this work. Special appreciation is accorded to Mr. A. J. Connor and other members of the Dominion Meteorological Service for the use of unpublished data which has been employed in the construction of some of the charts. The charts themselves are the work of Miss Peggy Clarke to whom the writers are deeply grateful.

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THE RACHITOGENIC PROPERTIES OF CEREALS IN CHICK RATIONS[1]

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[Received for publication November 10, 1937]

INTRODUCTION

Cereals have been shown, by several investigators, to contain some factor antagonistic to the calcifying action of vitamin D. From a long series of experiments, E. Mellanby (23, 24, 25, 26, 27, 28, 29) concluded that cereals contained an anticalcifying factor which had the effect of producing or intensifying rickets in dogs. Similar conclusions were drawn by Green and Mellanby (10) using rats. Oatmeal had decidedly the worst influence on bone formation, followed by corn (maize), barley, rice, and wheat flour, the last having the least effect. The action of oatmeal did not seem to be dependent upon the fact that it was a processed product since crushed whole oats and oat groats (oats with the hull removed) were just as potent. M. Mellanby (30) demonstrated the detrimental influence of cereals as judged by retarded tooth formation in dogs. She summarized the evidence as to the nature of this factor as follows: "It has been impossible to obtain evidence to show that the anti-calcifying action of cereals on the teeth is due to any known constituent. Neither the fat, carbohydrate, calcium and phosphorus (absolute and relative amounts), nor the acid-base ratio of the mineral constituents, explains this action of cereals. There is some evidence that it is associated with protein and liberated from it by proteolytic digestion." This rickets-producing effect was not limited to oats, barley, rye, wheat or corn but was present to a somewhat less extent in wheat and corn germ. The effect could be overcome by administration of extra vitamin D or by ultraviolet irradiation of the cereal.

Steenbock, Black and Thomas (37) reported that corn was the worst in so far as an anticalcifying agent was concerned, followed by rolled oats and wheat. Later (38) they compared the calcifying properties of diets containing different cereals with supplements of calcium carbonate and phosphoric acid, using the percentage of ash in the femurs of rats as the criterion. With the calcium carbonate supplements, their calcifying power was as follows: whole wheat, rolled oats and yellow corn, which was in order of their phosphorus content. Without calcium carbonate, wheat showed slightly less calcifying power than the other cereals. When the phosphorus content was equalized, by the addition of phosphoric acid, the order of calcifying power was reversed, demonstrating that equality of phosphorus intake was not the sole reason for the difference in calcifying action of the various cereals. De Wildt and Brouwer (8) also found corn to be more rachitogenic than oats and more so than barley, rye or wheat. Steenbock and Kletzien (39) improved the calcifying properties of rolled

[1] A contribution from the Department of Poultry Husbandry, Ontario Agricultural College and from the Department of Medical Research, Banting Institute, University of Toronto. The authors gratefully acknowledge the assistance and advice of Professor W. R. Graham and Dr. E. J. King. A part of this work formed the undergraduate thesis submitted by one of the authors (J. E. S.) in fulfilment of the requirements for the degree of Bachelor of Science in Agriculture. This thesis was awarded the Canadian Feed Manufacturer's Prize for the best thesis in Animal Nutrition, 1933.

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oats, wheat, corn and rice by heat treatment and by cooking. The decalcifying substance was found to be concentrated in wheat germ oil and present in large quantities in wheat gluten but they were unable to isolate it.

Templin and Steenbock (40, 41) discovered that the anticalcifying action of corn increased as the corn reached maturity. Permitting the corn kernel to germinate had no effect on these anti-calcifying factors but autolysis of the germinated corn destroyed them. Thomas and Steenbock (42) compared the relative rachitogenic properties of yellow corn, wheat, flour and polished rice. No significant difference in the severity of rickets in young rats was observed.

Holst (16) and Mellanby (24) were able to get rid of the anti-calcifying agent or "toxamin" in oatmeal by prolonged boiling with one-half to one per cent hydrochloric acid. Holst found the hydrochloric acid extract to be highly rachitogenic. It would appear that a short period of boiling with dilute acid appeared to bring the factor into solution, while longer boiling destroyed it. Mirvish (33, 34) and Mirvish and Bosman (35) confirmed the anti-calcifying action of this extract which they termed "Calcovarin" and produced a fall in blood calcium by its injection. Fine (9) confirmed the variations in the calcifying powers of cereals but attributed these to differences in vitamin D content. Gyorgy, Popoviciu and Sano (11), using rats, reported that corn had the strongest rachitogenic action followed by oats, rice and wheat with barley having little effect. Although oats had the highest phosphorus content, raising the phosphorus content of the other diets by the addition of dibasic sodium phosphate did not alter the degree of resultant rickets nor the sequence. Ten per cent of sodium chloride minimized the action and hydrolysis of the cereals with HCl usually completely prevented it. Bruce.and Callow (7) reinvestigating the influence of cereals on rickets in rats fed the usual type of rachitic diets, concluded that the "apparent rachitogenic effect of cereals when compared with other material of the same phosphorus content is due to the fact that cereal phosphorus is not in an available form," being largely phytin phosphorus or inositolhexaphosphate. The work of Booth, Henry and Kon (1) with rats fed rachitogenic diets supported this conclusion. McGowan and Emslie (31) discussed the relation of this "delayed" action type of phosphorus to bone disorders in chicks, particularly rickets and perosis. On the other hand Harris and Bunker (14) failed to find any relationship between the rachitic properties of different corn samples and either the absolute or relative amounts of phytin phosphorus.

King and Hall (18) concluded that the addition of oat groats to chick rations induced a more severe rachitic condition. Prolonged boiling of the groats with hydrochloric acid, without subsequent dialysis, appeared to render the anti-calcifying substance more available. Vitamin D tended to overcome this effect. Lachat and Palmer (21) repeated these experiments but were unable to show that oat groats was more rachitogenic than yellow corn. Incidentally in attempting to feed various concentrates from oatmeal, prepared essentially according to Mirvish (34), to chicks and rats, they encountered toxicity, apparently due to a high NaCl content. Using rachitogenic diets, they concluded that "hydrochloric acid extracts of oats, when purified and freed from excessive amounts of salt, may exhibit rachitogenic properties when fed to rats in a mildly rachitogenic diet, but

not when the ration is severely rachitogenic. Rolled oats and yellow corn are rachitogenic to rats and chicks, especially to the latter, and rolled oats appears to be more rachitogenic when the rations are otherwise only mildly rickets producing or the susceptibility of the animals is low."

Branion (2, 3, 4, 5) reported that corn contained some factor or factors responsible for the development of deformed legs in chicks, including bending, bowing[5] and "slipped tendons" or perosis. The reverse conclusion was equally tenable, namely, that corn lacked some factor or factors which allowed the development of perosis. This incidence of perosis in chicks with a large intake of corn has been confirmed by Schaible (36), and by Wilcke (43, 44). Wheat germ, oats, oat dust (shorts and germ) and oat feed (hulls, shorts and germ) were preventive. Halpin and Holmes (13) were unable to corroborate these findings, no differences being detected between the bones of lots of chicks fed on rations containing oat meal, corn, wheat and barley respectively. The literature dealing with perosis is too voluminous to warrant inclusion in this paper. It has been recently reviewed by Jukes (17) and Branion (6). Suffice it to say that perosis can be produced by excessive minerals, particularly phosphorus, in the ration, and that manganese is a preventive factor. Miller and Bearse (32) observed perosis in birds on corn or barley rations but not in the birds fed oats or wheat. The manganese content in milligrams per 100 grams of grain was oats, 4.66, wheat 2.91, barley 1.19 and corn 0.38.

EXPERIMENTAL

This experiment was planned as an investigation of the effect of cereal grains on avian bone formation with graded doses of vitamin D. Viosterol[6] (irradiated ergosterol) 250D was used as the source of the antirachitic vitamin. Since Mellanby had shown that the antagonistic influence of the cereals could be overcome by adequate supplies of vitamin D and that this effect became increasingly evident with subminimal amounts, and Hall and King (12) had shown that 20 mg. (1 drop) daily of viosterol was adequate for normal calcification, it was considered that doses of 2 drops, 1 drop, ½ drop (1 drop every second day) and ¼ drop (1 drop every fourth day) should provide a suitable range.

Two series were studied; in the first, ground oat groats were used, and in the second, in order to investigate any difference due to the hulls, ground oats were used. A basal supplement consisting of meat meal (60% protein) 10, dried buttermilk 10, iodized salt 1, and calcium carbonate 1 pound respectively, was used with all rations. The various rations are shown in Table 1.

Rations 5 and 10 closely approximate commonly used chick rations and served as controls. Another group was included in the second series, as a further control, receiving the same ration as 10, but supplemented with 2% of cod liver oil. In view of the known injurious action of corn, two extra groups were included in series 1, receiving ration No. 1, and 2½ and 3 drops daily of viosterol respectively. These groups can be dis-

[5] The leg bones of the chicks are often bowed out. Either the tibiae and metatarsals are malformed, although their ash content is normal, or the tibia-metatarsal joint is not normal, permitting the onset of bowed legs. Although the "stage is set" the tendons do not slip. Similarly chicks with bent legs are knocked-kneed, with the tendons in place, and the condition may be a result of malformation of either the leg bones or the joint.

[6] We gratefully acknowledge the kindness of Mead Johnson and Company, who donated generous amounts of viosterol for this work.

missed from further discussion with the statement that the extra vitamin D had no influence in preventing perosis. The viosterol was administered orally.

TABLE 1.—PERCENTAGE COMPOSITION OF RATIONS

Ration	1	2	3	4	5	6	7	8	9	10
Ingredients										
Basal	22	22	22	22	18	22	22	22	22	18
Corn	60	6	6	6	20 5	60	6	6	6	20 5
Wheat	6	60	6	6	20 5	6	60	6	6	20 5
Groats	6	6	60	6	20 5	—	—	—	—	—
Oats	—	—	—	—	—	6	6	60	6	20 5
Barley	6	6	6	60	20 5	6	6	6	60	20 5
Calcium	1 40	1 42	1 42	1 42	1 17	1 40	1 42	1 44	1 42	1 18
Phosphorus	0 74	0 77	0 78	0 75	0 69	0 74	0 77	0 78	0 75	0 69

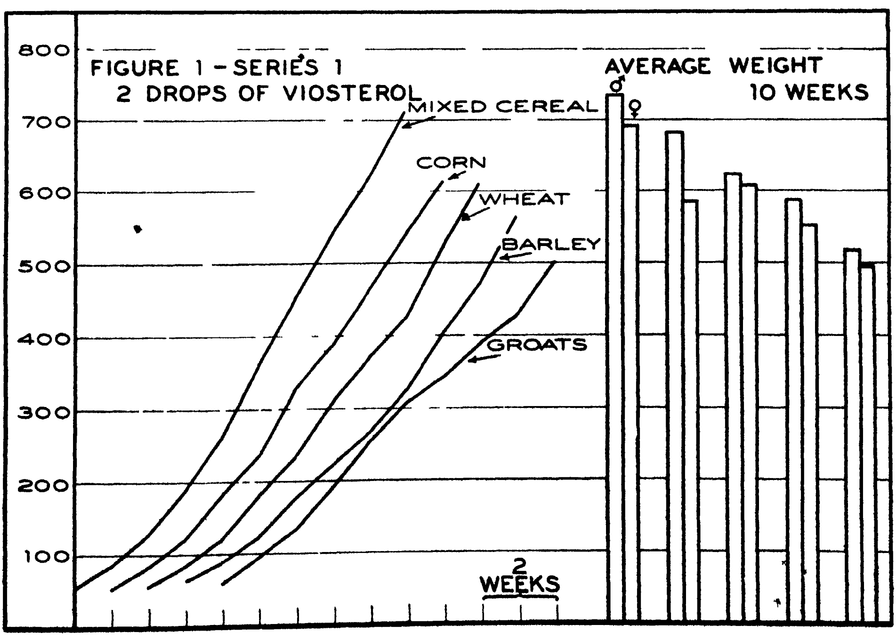
Fifty newly-hatched Barred Plymouth Rock chicks were used in each group. They were weighed individually once a week for 10 weeks. Growth curves are shown in Figures 1 to 8, together with the average weights of the cockerels and pullets at 10 weeks. The cereal grain composing the major portion of the ration is used to indicate the various groups. The mean weekly weights are given in Tables 2 and 3 together with the number of birds surviving.

TABLE 2.—AVERAGE WEEKLY WEIGHTS (GRAMS) IN SERIES 1 (GROATS)

Ration	Viosterol	Weeks										Number birds surviving
		1	2	3	4	5	6	7	8	9	10	
Mixed cereal	2% c l o	48	75	117	176	261	363	478	582	683	824	42
	2 drops	52	83	126	186	260	343	454	542	618	710	44
	1 drop	51	83	126	186	251	356	455	523	620	723	40
	½ drop	60	75	120	167	222	274	340	393	430	509	38
	¼ drop	65	81	123	171	235	280	337	383	424	470	36
Corn	3 drops	52	70	100	144	207	285	352	423	410	567	16
	2½ drops	51	69	97	140	218	295	365	433	540	590	15
	2 drops	55	80	118	179	236	325	387	462	541	614	34
	1 drop	52	74	108	164	229	311	403	488	582	679	30
	½ drop	59	81	118	175	239	313	391	449	522	603	40
	¼ drop	54	79	120	179	246	315	385	449	514	596	37
Wheat	2 drops	55	81	121	179	233	305	367	427	518	613	34
	1 drop	59	82	112	163	219	299	360	425	500	575	32
	½ drop	57	80	114	168	229	291	347	402	468	572	32
	¼ drop	59	80	116	172	234	295	343	400	456	516	29
Groats	2 drops	67	97	133	197	257	307	339	385	423	501	37
	1 drop	63	97	136	191	248	296	332	402	482	561	41
	½ drop	49	87	127	184	246	310	358	399	458	542	36
	¼ drop	51	90	123	167	197	250	264	301	342	384	25
Barley	2 drops	61	81	121	175	223	268	320	401	473	568	42
	1 drop	54	95	127	180	227	280	307	359	416	488	32
	½ drop	57	85	119	148	204	233	253	286	368	439	39
	¼ drop	52	86	121	159	205	237	256	310	372	468	28

TABLE 3.—AVERAGE WEEKLY WEIGHTS (GRAMS) IN SERIES 2 (OATS)

Ration	Viosterol	Weeks										Number birds surviving
		1	2	3	4	5	6	7	8	9	10	
Mixed cereal	2 drops	55	73	101	153	244	289	369	428	532	615	32
	1 drop	51	86	117	170	231	308	369	435	476	540	49
	½ drop	53	76	118	160	237	270	351	395	469	573	33
	¼ drop	52	74	111	158	212	266	275	358	391	454	36
Corn	2 drops	51	73	104	143	202	277	370	446	530	613	33
	1 drop	56	71	110	148	196	279	373	449	529	619	32
	½ drop	52	84	107	154	200	265	344	435	523	595	24
	¼ drop	52	81	104	144	200	288	366	459	541	597	23
Wheat	2 drops	51	81	119	161	249	260	283	337	387	482	27
	1 drop	52	81	119	152	237	253	273	314	366	479	17
	½ drop	52	78	117	157	215	257	297	333	394	492	28
	¼ drop	57	78	126	158	191	219	273	297	305	391	22
Oats	2 drops	47	76	111	156	211	268	357	457	564	613	37
	1 drop	48	86	102	146	193	264	367	467	535	592	36
	½ drop	55	78	106	158	195	256	353	418	513	602	33
	¼ drop	56	87	118	164	204	251	288	326	370	402	7
Barley	2 drops	50	65	100	144	192	253	307	391	442	527	15
	1 drop	50	75	123	159	200	251	293	342	362	467	13
	½ drop	59	80	114	147	191	237	287	324	254	172	2
	¼ drop	53	82	110	127	176	205	262	275	246	229	1



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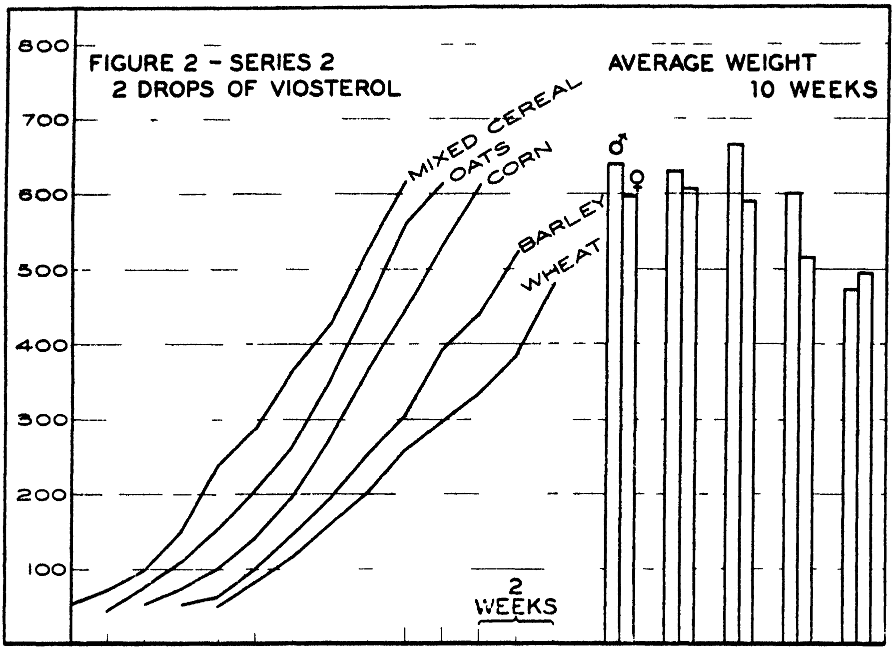


FIGURE 2 - SERIES 2
2 DROPS OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
MIXED CEREAL
OATS
CORN
BARLEY
WHEAT
♂
♀
2
WEEKS
800
700
600
500
400
300
200
100

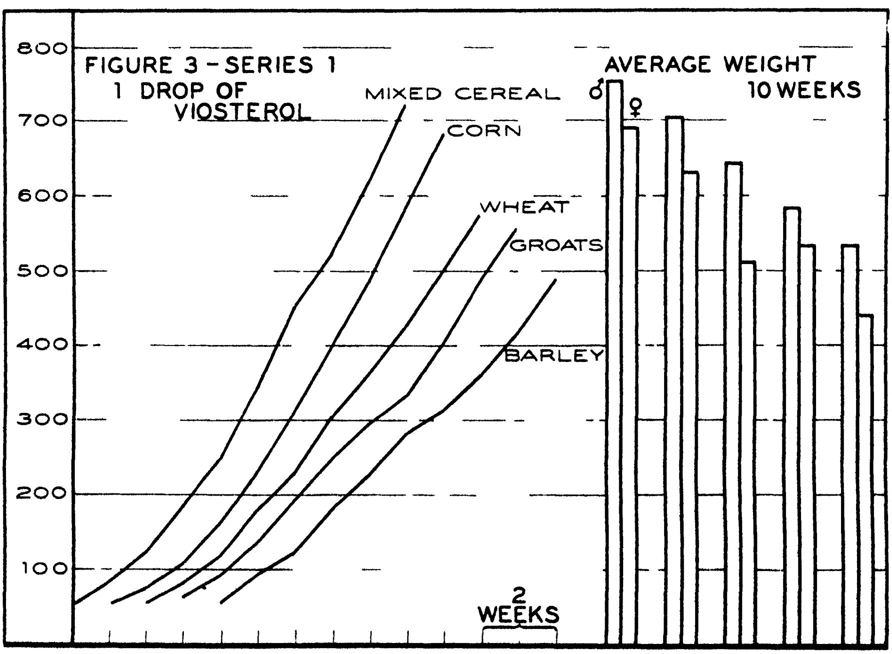


FIGURE 3 - SERIES 1
1 DROP OF
VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
MIXED CEREAL
CORN
WHEAT
GROATS
BARLEY
♂
♀
2
WEEKS
800
700
600
500
400
300
200
100

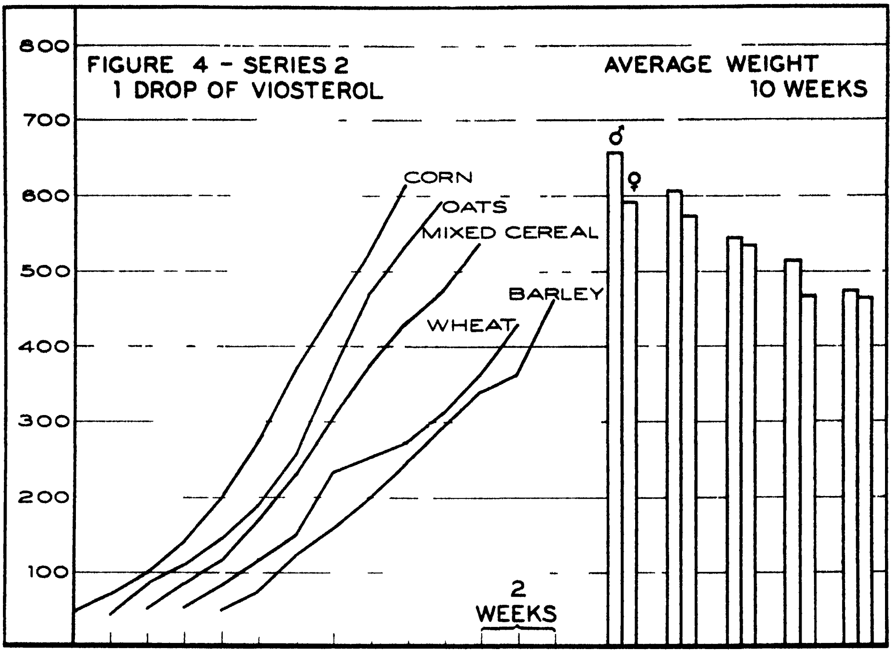


FIGURE 4 - SERIES 2
1 DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
CORN
OATS
MIXED CEREAL
BARLEY
WHEAT
2
WEEKS
♂
♀

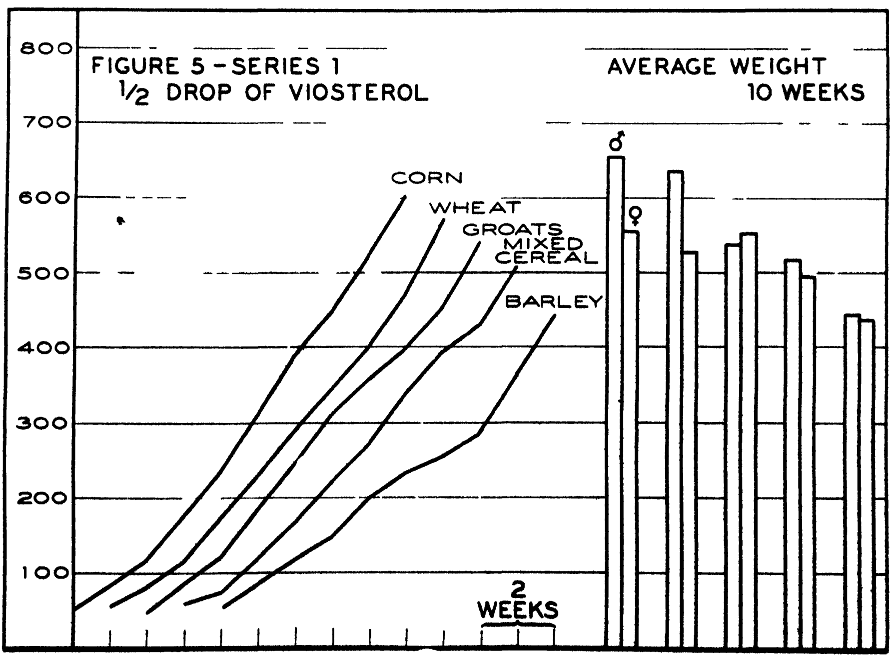


FIGURE 5 - SERIES 1
1/2 DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
CORN
WHEAT
GROATS
MIXED
CEREAL
BARLEY
2
WEEKS
♂
♀

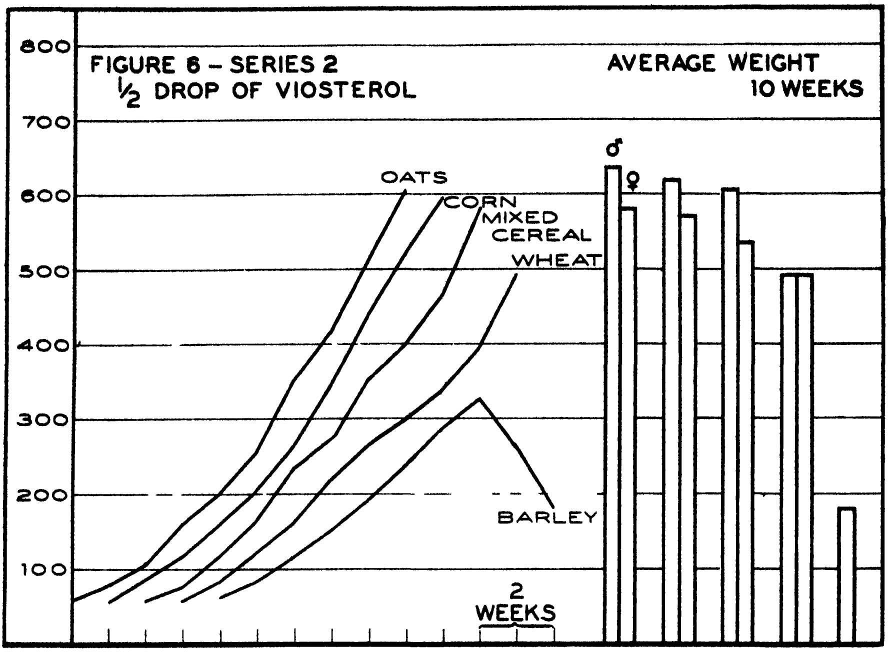


FIGURE 6 – SERIES 2
½ DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
OATS
CORN
MIXED
CEREAL
WHEAT
BARLEY
2
WEEKS
♂
♀

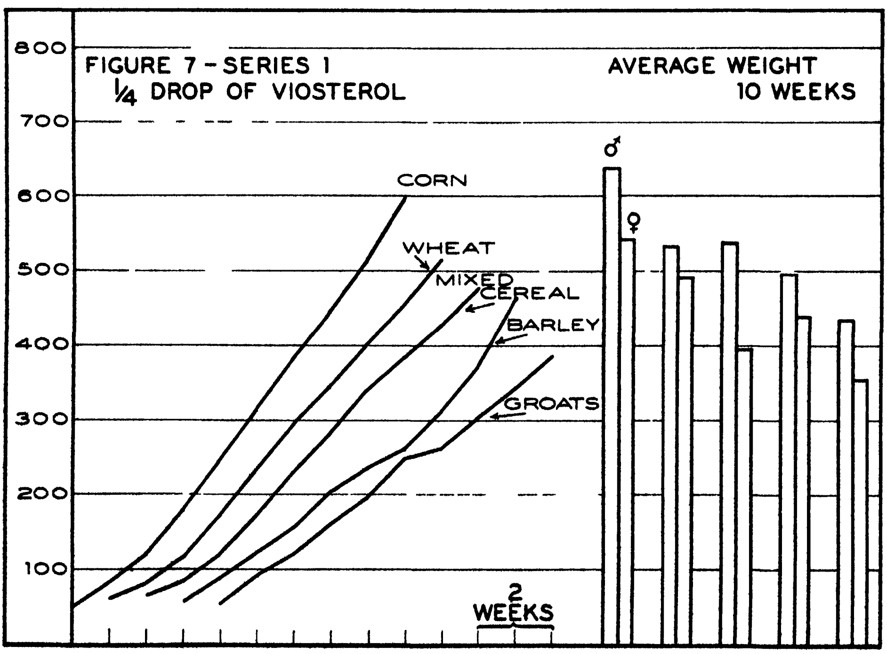
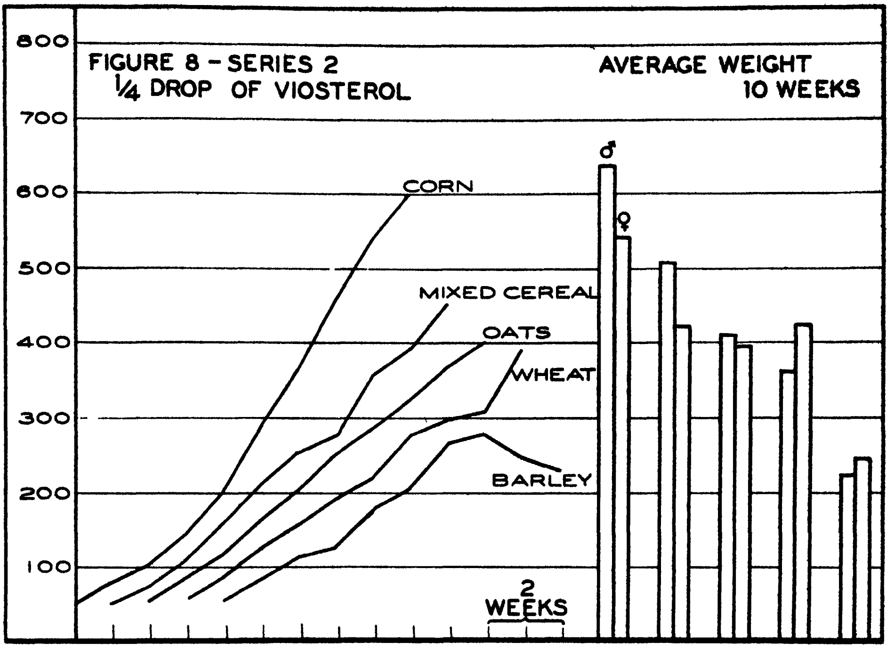


FIGURE 7 – SERIES 1
¼ DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
CORN
WHEAT
MIXED
CEREAL
BARLEY
GROATS
2
WEEKS
♂
♀



Growth and Mortality

An examination of the growth response indicates that the results are complicated by two factors, the growth-promoting properties of the various amounts of vitamin D, and the growth-promoting properties inherent in the cereal grains. In general, growth is lessened with decreasing amounts of vitamin D, although 1 drop (20 mg.) of viosterol daily gave growth not significantly lower than 2 drops. The growth response to the individual cereals with similar amounts of vitamin D confirms, in general, the results of Branion (5) who showed that growth of chicks varied with the kind of cereal grain used. These results also confirm the finding that the general trend in growth and livability favours a mixture of cereals rather than single cereals, providing the remainder of the ration is adequate.

An interesting observation arises pertaining to the difference in growth with the respective rations when oats are substituted for oat groats. With a mixture of cereals and with wheat, the trend in growth favours the oat groats, whereas with corn and barley there is no apparent significant difference. Oats gave better growth than oat groats when they formed the major part of the cereal mixture. Since the birds grew fairly well on the rations containing a high percentage of ground oats, when adequate vitamin D was provided, it would indicate that chicks can withstand a higher fibre content in the ration than would generally be considered.

It should be noted in series 2, that in those pens receiving oats or barley with the lower intakes of viosterol there was a high mortality, such that the growth curves are not significant after 8 weeks for that group receiving oats with ¼ of a drop of viosterol and those receiving barley with ⅛ or a ¼ of a drop. This mortality was not found in the wheat or corn groups. These facts would suggest that there may be some toxic factor in the oats

and barley, although this was not shown in series 1, and absent from the corn and wheat (or present in much smaller amounts) which the presence of adequate amounts of vitamin D tends to counteract. The reverse conclusion may, of course, be the proper explanation, namely that there is present in the wheat and corn some beneficial factor which is absent from the oats and barley. Most of this mortality occurred during the last three weeks of the experiment, the birds dying in convulsions. Post mortem examination gave no indication of the cause of this mortality. It is perfectly obvious that all of these rations did not contain the same amount of vitamin A. In fact, one would be suspicious that some rations did not contain adequate amounts of this nutrient. Such an explanation would serve to explain this mortality, except that it did not occur with oat groats and barley in the first series.

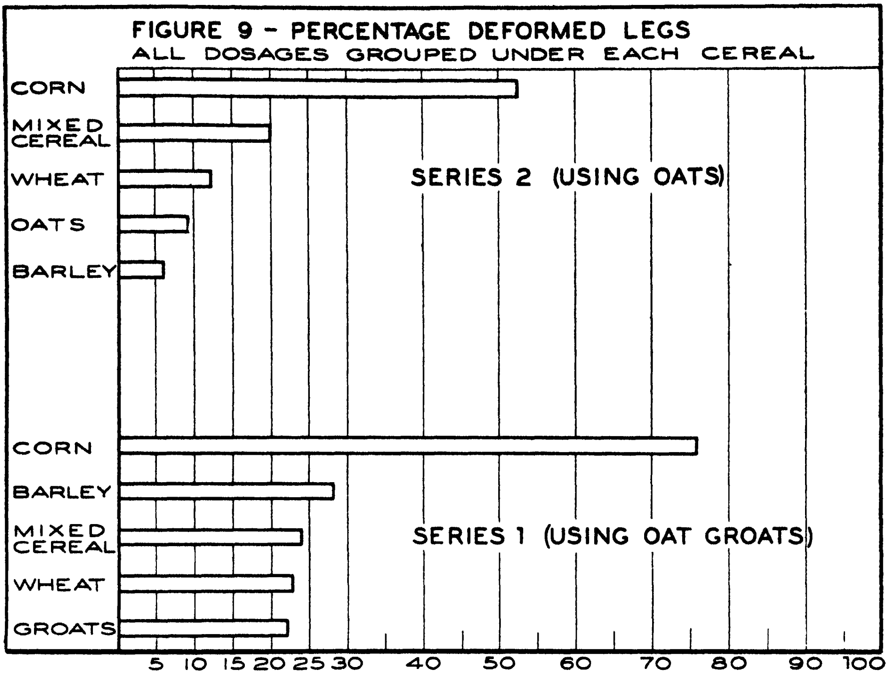
As would be expected, the general trend was towards increased mortality with suboptimal amounts of vitamin D.

Deformed Leg Development

The surviving birds were examined at the end of the experimental period for deformed legs, including bending, bowing and perosis or slipped tendons. The percentages of crooked legs for the cockerels and pullets in the various groups are shown in Table 4, and the crooked legs developed for all doses of viosterol with the individual cereals are shown in Figure 9.

TABLE 4.—PERCENTAGE OF DEFORMED LEGS

Ration	Viosterol	Series 1 (Groats)		Series 2 (Oats)	
		Cockerels	Pullets	Cockerels	Pullets
Mixed cereal	2 drops	10.5	12.0	35.3	26.7
	1 drop	13.6	10.0	22.7	18.5
	½ drop	36.0	30.8	21.0	7.1
	¼ drop	36.8	41.2	20.0	9.5
	C.L.O.	25.0	0.0	—	—
Corn	3 drops	62.5	37.5	—	—
	2½ drops	85.0	60.0	—	—
	2 drops	90.0	75.0	66.7	52.4
	1 drop	86.6	62.5	35.7	38.9
	½ drop	94.4	72.7	62.5	60.0
	¼ drop	68.2	60.0	57.1	50.0
Wheat	2 drops	23.5	29.4	18.2	12.5
	1 drop	6.2	0.0	8.3	0.0
	½ drop	23.5	25.0	7.1	7.1
	¼ drop	5.0	16.7	30.0	16.7
Oat groats	2 drops	50.0	18.2	—	—
	1 drop	20.0	12.5	—	—
	½ drop	17.7	7.1	—	—
	¼ drop	10.0	40.0	—	—
Oats	2 drops	—	—	7.7	10.5
	1 drop	—	—	11.1	0.0
	½ drop	—	—	0.0	5.9
	¼ drop	—	—	—	—
Barley	2 drops	22.7	10.0	0.0	25.0
	1 drop	27.8	38.4	25.0	0.0
	½ drop	20.0	37.5	—	—
	¼ drop	46.7	23.1	—	—



It seems evident that these deformed legs were due to two causes, the cereal used and the dosage of vitamin D. The lower dosages of viosterol resulted in the onset of rickets as is borne out by the percentage of bone ash. However, as will be pointed out, deformed legs cannot be used as an absolute criterion. Since the use of a mixture of cereals, containing equal parts of each cereal, overcomes the characteristics of the individual cereals in relation to bone development, the groups fed on the mixture should give a clear indication of the differences in leg abnormalities due to rickets. These groups show a decreasing percentage of deformed legs with an increase in the amount of viosterol fed in series 1 where oat groats were used. In series 2, using oats, the results are almost the reverse, and indeed appear so unreasonable that no conclusions can be drawn.

The influence of the individual cereal grains on bone development is evident. These results show the tendency of chicks fed a high intake of corn to develop abnormal legs, confirming the perosis-producing properties of this cereal. This is not a rachitic condition since it developed with rations containing adequate amounts of vitamin D. An examination of Figure 9 shows that the substitution of ground oats for ground oat groats has alleviated the abnormality to a considerable extent. This substantiates the finding that oat hulls as well as the hairs between the kernel and the hull (which are partially removed during the manufacture of the groat) contain some factor which prevents perosis.

Percentage Ash of Leg Bones

The percentage ash of the fat-free femur, tibia and metatarsus of the surviving chicks in each group was determined on aliquot portions of the

combined bones. The results are shown in Table 5. As a comparison, the percentage ash of a similar group fed on a good commercial ration was determined to be 52.2%. The mixed cereal group fed 2% of cod liver oil had a 51.1% of ash in their leg bones.

TABLE 5.—PERCENTAGE ASH OF LEG BONES OF CHICKENS FED DIFFERENT CEREALS

Cereal	250 D viosterol administered daily			
	¼ drop	½ drop	1 drop	2 drops
Mixed (groats)	40.5	48.3	50.4	50.0
Mixed (oats)	40.7	46.1	46.8	49.8
Corn (groats)	43.4	45.7	48.7	50.3
Corn (oats)	46.4	46.7	46.5	45.1
Wheat (groats)	44.1	44.5	49.1	49.6
Wheat (oats)	44.9	45.7	48.1	48.7
Groats	46.4	47.7	48.1	48.9
Oats	43.2	48.7	49.8	50.9
Barley (groats)	47 3	47.1	48.7	50.3
Barley (oats)	—	—	48.3	49.3

These determinations were made on the vacuum-dried weight of bone. The percentage ash on air-dried basis was 3 to 4% lower.

These results suggest that the individual cereals do exert some influence on bone development. This cannot be explained on the basis of their calcium and phosphorus content, since this was approximately the same in all rations, with the exception of the mixed cereal groups, and the levels in all rations were within the accepted range.

There was a decided difference in the gross appearance of the bones. The bones of the corn-fed chickens were large, coarse and somewhat pithy; presumably the organic matrix is somewhat porous and open, although the ash content is normal. The oats and oat groat bones were smaller and finer, although on removal from birds of about the same weight they weighed more than the corn bones. The bones of the wheat fed groups were intermediate between barley and oats. The barley bones also tended to be somewhat coarse.

Arranging the cereals in order of rickets-producing effect, as judged by percentage bone ash, showed no definite order of deleterious action on bone formation. The analyses do not offer any evidence that oats or oat groats contain an anticalcifying factor in excess of other cereals.

The variations observed cannot be satisfactorily explained. Because of the somewhat unsatisfactory nature of the results of the chemical analyses of the bones, probably not too much stress should be laid on this phase of the results. They do indicate that about 20 mg. (1 drop) daily of 250D viosterol (irradiated ergosterol) results in normal calcification. They further give additional confirmation of the inefficiency of irradiated ergosterol, rat unit for rat unit, as compared to cod liver oil in promoting calcification in chicks.

In interpreting the results of any such experiment, the influence of rate of growth upon calcification or bone development is a complicating factor and this variable would seem to be difficult to overcome. Harshaw, Fritz and Titus (15) concluded that much of the variation among individual

chickens of the ash content of their leg bones was due largely to differences in their rate of growth. Their results could be interpreted broadly to mean that the ash content of slower-growing birds is greater than that in the bones of faster-growing birds fed the same ration. The work of LeMasurier and Branion (22) confirmed this suggestion, indicating that the degree of severity of rickets is directly proportional to the amount of growth which the bird has achieved. On the other hand, Lachat and Halvarson (20) claimed that birds growing slowly have a lower ash content than faster-growing birds, that is, that calcification is greatest in the larger birds. Lachat (19) further reported positively significant correlations between size and calcification, heavier birds having a higher bone ash content than lighter ones.

No matter which conclusion is correct, it is obvious that rate of growth does influence bone development. This must be borne in mind in the consideration of any results, based upon percentage bone ash, such as reported herein. The rate of growth and the final weig t achieved by the various groups are not the same. Even paired-feeding methods, r feeding methods designed to achieve a uniform rate of growth in all groups will not suffice, since the rate of growth of those birds on the diet which would give, under *ad libitum* feeding, the greatest growth, is being lessened with its subsequent effect upon calcification.

SUMMARY

No definite evidence that oats or oat groats contain any anti-calcifying factor in excess of corn, wheat or barley was obtained. The percentage of ash in the leg bones of 10-week old chickens did indicate some differences in bone development, due to the cereal used, but these could not be explained upon the calcium or phosphorus content of the grains.

Further evidence is presented to show the association of a high corn intake with perosis and the preventive properties of oat hulls and the hairs between the hull and kernel.

Differences in growth response and mortality in the chicks is shown to be related to the cereal grain in the ration. In general, increasing amounts of vitamin D, up to the optimum level, increase growth and lessen mortality.

Irradiated ergosterol is shown again to be inefficient as compared to cod liver oil in promoting calcification, about 20 mg. daily of 250 D viosterol being required.

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

II. The Flight of the European Corn Borer. Annual Cycle of Flight. Daily Rhythm of Flight. Flight to Light Trap.

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[Received for publication January 12, 1938]

REVIEW OF LITERATURE

Only the general references will be given and discussed at this point. The literature referring to restricted considerations or phases of flight will be discussed when these topics are considered below.

Jablonowski (20) in 1898 made the first recorded observation on the flight of the corn borer. He observed that in Hungary adults emerge about the middle of June and the beginning of July, although some moths emerged as early as May and others as late as August. Vinal (30) published in 1917 the first observations on the flight of the insect in North America. In the bivoltine type of borer found in Massachusetts he noted that moths began to emerge during the latter part of May. Two years later, Vinal and Caffrey (31) reported that in Massachusetts the moths remain inactive during the day, when they may be found hiding on the under surface of the foliage of their food plant or in strips of grassland and low weeds. They also remain inactive during cool periods and during high winds according to these authors. They conclude that the moths become active in late afternoon and reach their greatest period of activity about dusk.

Jablonowski (21), who compiled statements of his observations on the borer in Hungary at the request of the United States Bureau of Entomology and Plant Quarantine, records the fact that the moths begin to fly at the beginning of June. He observed their emergence in a blossoming clover field in the dusk of the evening and states that by nightfall incredible numbers had appeared. He also reports an observation made in 1904 by L. Baross who captured moths at an acetylene light and found that they flew with greatest activity during the last of June and first week of July. In the same publication, Jablonowski states that moths fly at sunset and continue until it becomes completely dark, whereas in the daytime the moths fly only when disturbed.

Spencer (26) in Ontario, noted that at Port Stanley, during 1921 and 1922, the moths did not begin to move freely until about 9 p.m., although a few commenced to move just after dusk.

Barber (4) studied the oviposition of adults during 1919-22 in the New England area, mostly under caged conditions. He does, however, state that moths are only active at night at which time they fly, mate and lay eggs. He correlated the egg-laying activity of the moths with night

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temperatures as will be discussed later. Barber (5) in 1926, showed the seasonal occurrence of flight and oviposition periods for 1922 in the New England area. He constructed charts from pupation and emergence records from caged material. The peak of emergence was apparently June 15 for the first generation.

Poos (24), working in Ohio in 1925-26 observed that although the moths have not been observed to fly any great distances in the daytime, their period of greatest activity is at night.

Caffrey (8), in his general bulletin on the corn borer in the United States, states that the moths are essentially nocturnal in habit, although individuals have been observed taking short flights during daylight. He noted influence of temperature upon flight stating that moths are most active on warm nights and comparatively inactive on cool or cold nights or during heavy winds. He also mentions that the daily period of greatest flight activity begins shortly after dusk and does not lessen materially until after three or four hours of darkness. He concludes with the statement that only a few moths have been observed in flight during the later hours of the night.

Huber, Kelsheimer *et al.* (18) studied the flight in northern Ohio, especially in regard to the physical factors concerned and the planting date of the corn. No seasonal activity or numbers of moths in flight are given except in relation to a physical factor or planting date. These results will be discussed below. This is a very important study of the behaviour of the corn borer adult and the paper will be referred to on various occasions.

The next series of papers to occur on flight are two papers by Stirrett during 1929 (27, 28), and one paper by Stirrett, Beall and Lindsay in 1934 (29) These are brief preliminary papers dealing with certain observations made during the progress of the present study and need not be discussed as they are superseded by the present report.

Bottger and Kent (7) studied the seasonal history of the borer in Michigan during the years 1926-30 inclusive They give the date of maximum emergence of moths as follows: in 1928—July 11; in 1929—July 1; in 1930—June 29. They did not study the flight itself, but give considerable data regarding oviposition which will be discussed under that heading.

Summary of Literature on Flight

Practically nothing has been published regarding the flight habits of the corn borer other than the fact that they appear at certain seasons, fly at dusk or during darkness, with their greatest activity two or three hours after flight commences. The only papers giving any definite information are those of the author which deal with certain preliminary observations made in the present long-term study.

THE ANNUAL CYCLE OF FLIGHT

The annual or seasonal cycle of flight has been measured by systematic observations in the standard plot "A" each year from 1927 to 1936, inclusive, and in supplemental plot "B" in certain years. It has also been measured from light trap catches during the years 1931 to 1936, inclusive.

(A) The Annual Cycle of Flight in Corn Fields, Plot "A"

The results of these studies can best be presented in the form of histograms as by this method one is enabled to see at a glance the records for a number of years at a time. The histograms of flight in plot "A" and from light trap are made to the same scale for direct comparison, and show the number of moths observed in plot "A" each night during the flight period between the sunset hours of −30 and 4:30 inclusive (approximately 7:30 p.m. to 12:30 a.m. each evening). The very small morning flight discussed later is not included.

In order to understand the significance of the discussion, it should be explained that the moths are not found within corn fields during the daytime. In ten years' experience with this insect only one moth has been seen in a corn field during the daytime, although hundreds of fields have been visited in the course of regular entomological work in the district. The moths fly to the corn field each night and fly away from it during the same night at the termination of flight. The drift to corn fields after dark is quite easy to observe as is also the drift of moths away from the fields later in the evening. It has been observed by us on a number of occasions without securing definite records of numbers of moths. Huber (18) records the movement in and out of a corn field in Ohio watched by eight men, two to each side of the field during the night. They found that up to ten o'clock all movement was into the field, while after that hour the outward was pronounced. A total of 577 moths were observed to enter the field and 416 to leave the field.

The Seasonal Limits of Flight

The seasonal limits for each year for flight within plot "A" have been shown in Table 1 and in Figures 1 and 2 were made.

TABLE 1.—SEASONAL LIMITS OF FLIGHT, CHATHAM, ONTARIO, 1927–36

Year	Date of commencement of flight	Date of apparent peak of flight	Date of termination of flight
1927	July 8	July 12	Aug. 7
1928	July 7	July 16	Aug. 9
1929	July 4	July 7	July 31
1930	June 29	July 8	July 24
1931	June 30	July 9	July 23
1932	June 28	July 7	July 24
1933	June 24	June 29	July 20
1934	June 29	July 12	July 23
1935	July 5	July 11	July 24
1936	June 28	July 9	July 24
Average date for all years	July 1	July 9	July 27

Up to and including the year 1933, there is an apparent tendency for flight to take place earlier each year. This tendency, had it been continued, would have been a boon to growers in regard to date of planting to escape infestation as corn could have been planted earlier and still escaped the borer. Unfortunately, such did not occur and in 1935, especially, the date of commencement of flight is quite late.

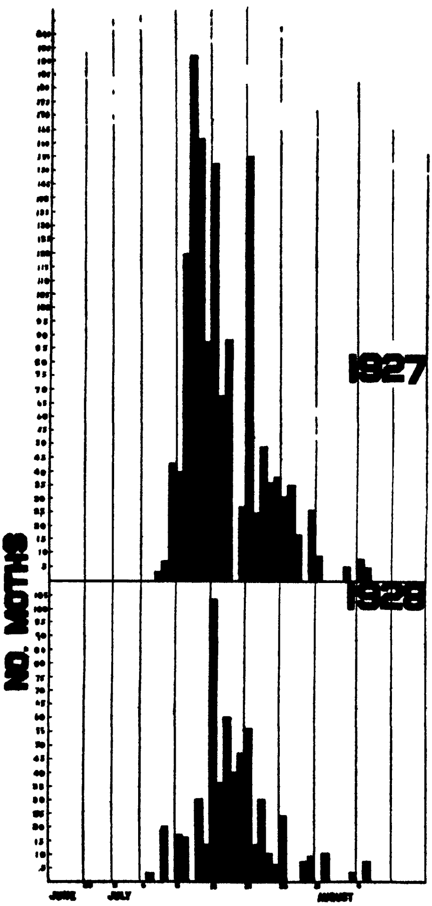

FIGURE 1. Annual flight of moths, Plot "A", Chatham, Ontario, 1927–28.

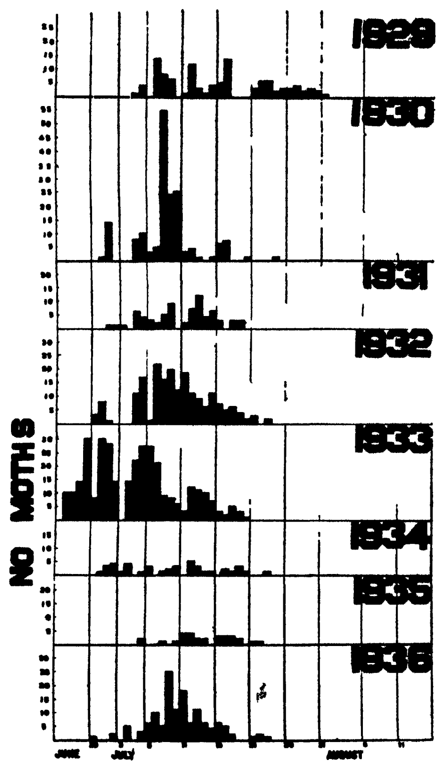

FIGURE 2. Annual flight of moths, Plot "A", Chatham, Ontario, 1929–1936.

The seasonal limits of flight are very close to those given by Bottger and Kent (7) for southern Michigan. These authors were stationed at Monroe, some 90 miles west and south of Chatham. Judging their records of oviposition as indicative of moth flight in their region, data from their publication shows the seasonal flight in southern Michigan to be very similar in seasonal limits to that of Chatham.

TABLE 2.—SHOWING SUMMARY OF OVIPOSITION RECORDS, EUROPEAN CORN BORER, TAKEN IN A FIELD IN SOUTHERN MICHIGAN. FROM BOTTGER AND KENT, 1931

Year	Date first eggs observed	Date of maximum oviposition	Date last eggs found
1926	July 2	—	—
1927	June 24	July 14	July 31
1928	July 1	July 10	July 23
1929	June 20	July 9	Aug. 1
1930	June 17	July 7	July 17
Average	June 25	July 10	July 26

The time of commencement of flight depends upon the rate of pupation and pupal development from season to season. It has been shown by a number of workers that the date of pupation and the emergence of the moths from pupae depends to a considerable extent upon climatic conditions, especially temperature and moisture. We are not concerned with this phase of the problem in the present study.

The Duration of Flight Season

The duration of flight season may be measured in two ways, first, as shown in Table 1, by the length of the period between the commencement of flight and termination of flight, and second, by the total number of nights in which flight actually took place. The length of flight measured by these two criteria are compared in Table 3.

TABLE 3.—LENGTH OF FLIGHT PERIOD ACCORDING TO SEASONAL LIMITS AND ACTUAL NIGHTS OF FLIGHT, CHATHAM, ONTARIO, 1927–36

Year	Length of flight period in days	Actual nights of flight	Number of nights on which no flight took place in the season
1927	31	25	6
1928	32	22	10
1929	28	23	5
1930	26	17	9
1931	20	17	3
1932	26	22	4
1933	27	26	1
1934	25	19	6
1935	18	13	5
1936	27	21	6
Average for all years	26	20 5	5 5

The reason for the absence of moths on nights during the season when they would be expected to fly is discussed later under the influence of the physical factors upon flight.

The Magnitude of Flight

From an examination of Figures 1 and 2 it is readily seen that the number of moths in flight varied greatly from season to season. The actual number of moths observed each year is shown in Table 4.

TABLE 4.—MAGNITUDE OF MOTH FLIGHT, NUMBER OF MOTHS OBSERVED IN PLOT, CHATHAM, ONTARIO, 1927–36

Year	Total number of moths
1927	1431
1928	607
1929	108
1930	169
1931	72
1932	196
1933	335
1934	41
1935	29
1936	131
Average for all years	311 9

Any variation in the numbers of moths attracted to the corn plot must be due to factors outside the plot itself as it has been shown that the plots were planted at the proper time to attract the same number of moths as the great bulk of the corn crop of the district. That such was actually the case is seen by the very close relationship between the moth catch in our plots and the light trap, and in our plots and the supplemental farmers' plots "B", when these were planted at the same time as our plot "A".

We are not concerned in this paper with the history of the borer and moths before they fly to our plots, but it might be well to discuss briefly some of the factors which might influence the number of moths found in the plot.

The Enforced Annual Corn Debris Clean-up

Under the provisions of the Ontario Corn Borer Act, the Provincial Entomologist and county corn borer inspectors conduct an enforced clean-up of all corn refuse by the grower. The Act came into force in the autumn of 1926 in eight counties in southern Ontario, including Essex, Kent and Lambton, and has been maintained each year since. The annual clean-up began before our observations started, and as there has been very little variation in the thoroughness of the clean-up from year to year, it should have the same value annually in regard to its effect in the number of moths surviving. We are thus able to dismiss it as a factor which might cause a variation in the number of moths from year to year.

The Variation in Corn Acreage

One factor which might presumably have an effect on the number of moths present each season would be total corn acreage within a district. Table 5 shows that there is apparently no correlation between corn acreage and the number of moths in our plot. The values given for corn acreage have been compiled from the Annual Reports of the Statistics Branch, Ontario Department of Agriculture. Although this was the actual acreage of corn grown in these years, it must be remembered that the corn refuse clean-up took place between the time the corn was grown and the emergence of the moths the next season. Theoretically, at least, the acreage for each year was brought to about the same basis through the clean-up. This levelling process is more uniform than suspected as it must be remembered that only a portion of the entire crop is infested, the late planted corn being almost entirely free of borers. Furthermore, the inspectors pay particular attention to heavily infested fields and make sure they are cleaned up very thoroughly.

TABLE 5—TOTAL CORN ACREAGE FOR ESSEX, KENT AND LAMBTON COUNTIES AND TOTAL MOTHS IN FLIGHT AT CHATHAM, ONTARIO

Year	Total acres to nearest thousand, 000 omitted	Total number of moths in flight. Placed opposite the corn acreage from which they were derived
1921	191	—
1922	189	—
1923	201	—
1924	197	—
1925	151	—
1926	125	1431
1927	64	607
1928	79	108
1929	95	169
1930	99	72
1931	121	196
1932	127	335
1933	128	41
1934	147	29
1935	153	131
1936	151	—

If we assume that the corn acreage from year to year has little influence on the number of moths in flight during the next season because of the corn refuse clean-up, the factors influencing the numbers of moths available

for flight concern themselves with larval winter mortality, and larval and pupal mortality later in the season. As pointed out previously, larval winter mortality averages between 6 and 9% in the district. It has shown little variation from year to year and can be dismissed as a factor producing a variation in number of moths.

The Pupal Mortality

Pupal mortality must be one of the important factors, if not the most important, causing a variation in the number of moths from season to season. In 1934 it is known that 60% of the pupae were killed in one field examined on July 5. Sixty-six of the dead pupae were examined for stage of development and it was found that a great majority contained apparently fully formed adults, while others were only partially developed. Two were malformed, as the larval head was still attached to the typical pupal abdomen. Judging from experience, one would say that these pupae were killed from excessive heat and lack of moisture. Pupae were checked for the presence of pathogenic organisms by competent plant pathologists, but none were present. Unfortunately, pupal mortality records are not available for other years.

A. B. Baird, Entomologist in charge of Parasite Investigations, Entomological Branch, Dominion Department of Agriculture, formerly stationed at Chatham, states that during 1925 he noted some fields in which as high as 80% of the pupae were dead. D. J. Caffrey, Senior Entomologist, United States Bureau of Entomology and Plant Quarantine, formerly in charge of Corn Borer Investigations, has stated in conversation that he also had found very high pupal mortality in some fields in Ohio and at other points during 1925.

That there is a variation in pupal mortality from year to year, much greater than that of larval winter mortality, is shown by Bottger and Kent (7) for southern Michigan. In 1927, they state the pupal mortality was 9%, while in 1928 it was 8% and in 1930, it was 15%.

The death of the pupae in the field in 1934 took place between June 19 and July 5, as the pupal count on the former date showed only 1.8% mortality. The year 1934 was very hot and dry as may be seen from Table 6.

TABLE 6.—TEMPERATURE AND PRECIPITATION, MAY, JUNE and JULY, 1934, WITH DEPARTURES FROM NORMAL

Month	Mean Temperature	Departure	Total precipitation	Departure
May	61	+5	0 27	−2 70
June	74	+8	1.00	−1 64
July	76	+6	1.01	−1.80

The period in which the death of the pupae took place was very hot and dry. Table 7 gives the average daily temperature, average saturation deficiency, and rainfall for the period.

TABLE 7.—AVERAGE DAILY TEMPERATURE, SATURATION DEFICIENCY AND TOTAL RAINFALL, JUNE 19 – JULY 5, 1934

Date	Average daily temperature	Average saturation deficiency	Total rainfall in inches
June 19	70.6	7.36	
20	73.6	10.89	
21	75.3	10.05	
22	61.3	4.97	
23	70.4	7.49	
24	80.5	14.55	
25	70.2	9.62	
26	67.6	4.10	0.22
27	70.5	5.77	
28	80.7	11.43	
29	81.5	12.98	
30	77.2	10.11	
July 1	69.4	14.88	
2	75.7	11.46	
3	79.4	14.18	
4	67.8	7.09	
5	74.2	4.69	

It should be noted that at the time of the year this mortality took place, the clean-up of corn refuse had been completed, and all stalks in the fields were short pieces lying on the surface of the ground. The field in which the examination was made was weedy, but there was no shelter for the corn stalks lying on the soil or partly buried from the direct rays of the sun. Surface temperatures were not secured, but they must have been very high.

As will be shown and discussed later, it is thought that the high pupal mortality of 1934 was largely responsible for the great decrease in borer abundance which took place during this year.

Sex Ratio of Moths in Flight in Corn Fields

Sex Ratio of Pupae.—If pupae are examined in the field or collected from stalks in the field, it will be found that the sexes occur in about equal numbers. Vinal and Caffrey (31) found in the early years of the borer's history in America, that in Massachusetts in the bivoltine type, 42.3% of the first generation were males or 57.7% were females. Spencer (26), in Elgin County, Ontario, in the univoltine type borer found 56.38% males and 43.62% females in 1921, and 51.08% males or 48.92% females in 1922.

Caffrey (8) states that in Ohio, in the univoltine type borer, 46.7% are males and 53.3% are females. Poos (24) also working in Ohio found 46.1% males and 53.9% females in 1923 and 48.3% males or 51.7% females in 1924. Ficht (14), in unpublished work done at Chatham, Ontario, found the sexes about equally divided during 1925 and 1926. Hergula (16), on the other hand, working in Jugoslavia, found that females greatly dominated his cultures, 65% being females or 34% being males.

It would appear, therefore, that in North America, and in Ontario in particular, the sexes are fairly evenly divided in the corn debris.

Sex Ratio of Adults in Corn Field.—Very few males are captured within the corn field at night, as shown in Table 8.

TABLE 8.—PROPORTION OF MALES CAPTURED IN FLIGHT, PLOT "A", CHATHAM, ONTARIO, 1927–36

Year	Total catch, sex determined individually	Number of males	Per cent of total catch, males
1927	1431	0	0
1928	405	0	0
1929	108	4	3 7
1930	169	13	7 6
1931	72	6	8 3
1932	183	28	15 3
1933	277	92	33 2
1934	34	14	41 1
1935	21	4	19 0
1936	99	28	27 2
Average per cent for all years			15 5

The large proportion of males found in 1933, 1934 and 1936, is interesting, and possibly indicates that the normal activity of the males in these years was upset in some manner As will be shown later, in 1933 there were not only more males in the field than usual, but they flew earlier in the evening than was the habit of the moths in other years, thus again indicating some disturbing factor in their activity

It would appear that, normally, males do not frequent corn fields to any great extent. Mating does not take place in the corn fields, as in the ten years in review moths in copula have been noted only upon one occasion within a corn field Caffrey (8) makes the statement that moths copulate within twelve hours of emergence If this is so, then the moths probably mate in or near the field containing the corn debris from which they emerge.

Protandry.—A number of investigators including Crawford and Spencer (12), Ficht (14), Caffrey (8), Poos (24), and Hergula (16), have noted that the males begin to emerge from the pupae before females. Poos (24) determined during the seasons of 1924 and 1925, that approximately three-fourths of the individuals under observation had emerged before the proportion of males and females had become equal. This protandric tendency is not found in the flight of the moths to the corn fields. This is shown in Table 9.

TABLE 9.—NUMBER OF MALES IN FLIGHT AT TWO PERIODS OF FLIGHT SEASON CHATHAM, ONTARIO, 1927–36

Year	Period 1—first five days of flight	Period 2—second five days of flight
1927	0	0
1928	0	0
1929	0	1
1930	0	9
1931	1	1
1932	4	8
1933	11	15
1934	5	0
1935	1	2
1936	3	10
Total for all years	25	46

The Relation of Emergence to Flight in Field.—There is a period of a few days between the emergence of moths from pupae and the appearance of the moths in the corn field within the same region. This is shown in Table 10.

TABLE 10.—COMPARISON OF DATE OF EMERGENCE OF MOTHS AND BEGINNING OF FLIGHT IN CORN FIELDS, CHATHAM, ONTARIO

Date	Date of emergence and per cent emerged	Date of commencement of flight in corn field	Difference in number of days (later)
1927	June 24—2%	July 8	14
1928	June 28—3%	July 7	9
1929	July 3—	July 4	1
1930	June 13—4%	June 29	16
1934	June 19—1%	June 29	10

The length of the period is not constant from year to year. It is too long a period in most cases to be explained by the pre-oviposition period. Caffrey (8) states that the pre-oviposition period is from 2.6 to 5.1 days in Massachusetts, while Poos (24) found the average length to be 4.4 days in Ohio and Spencer (26) found it to be from 3.5 to 4 days in Ontario.

The protandric tendencies in emergence might explain part of the delay as the males are not attracted to corn as strongly as the females and it has been shown above that males begin emerging first. Another factor which might, in certain years, influence the length of this period is cool weather which would prohibit flight. This will be discussed fully later.

(B) The Annual Cycle of Flight in Corn Fields, Plot "B"

As has been noted previously under "Methods of Study", secondary farmers' plots of corn have been utilized in certain years. The flight plots within these fields have been the same size as plot "A", and records have been taken in a similar manner. As the plots were generally within a mile of the standard plot, the meteorological records taken in this plot are used for the analysis of flight in "B" plots. The records were actually taken in these plots after the regular hourly observations in plot "A" were completed, although they are recorded as being taken at the same time as the records in plot "A".

Complete records were taken for evening flight in "B" plots in the years 1929, 1931, 1934, and 1935, while partial records were taken in 1932 and 1933. The moth catch in the years 1929, 1931, 1934 and 1935 has been plotted on Figures 4, 6, 9 and 10, respectively, in Part III, together with the flight in plot "A" so that they may be compared.

The catches are remarkably similar in regard to magnitude of flight when the corn in the two plots of each year were planted on, or nearly on, the same date. This is shown in Table 11.

The early sweet corn plot, because of its much earlier maturity, attracted considerably more moths than our later corn plots. When the

plots were planted at or about the same date, and at the general planting date for the region, the number of moths attracted to the different plots, even if these were of a different variety and removed considerable distance from each other, was practically the same.

TABLE 11.—SHOWING MOTH CATCHES IN PLOTS "A" AND "B", TOGETHER WITH PLANTING DATES

Plot and year	Corn variety	Planting date	Number of moths observed
1929			
"A"	Wisconsin No. 7, white dent	June 6	108
"B"	Sweet corn	May 14	248+
1931			
"A"	Wisconsin No. 7, white dent	May 26 and 27	72
"B"	Yellow dent	May 20	81
1934			
"A"	Wisconsin No. 7, white dent	May 21	41
"B"	Yellow dent	May 22	43
1935			
"A"	Wisconsin No. 7, white dent	May 21	29
"B"	Yellow dent	May 22	30

The similarity of the behaviour of the moths and the daily rhythm of flight in these two plots will be discussed below under effects of the physical factors.

THE DAILY RHYTHM OF FLIGHT

The Time of Night of Flight

Table 12 summarizes the catches for all years according to Sunset time, and shows that for the ten years under review the great majority of the moths flew at and between the hours of :30 and 4:30 Sunset time. and shows the percentage of all moths flying at various hours and periods of the night.

TABLE 13.—PERCENTAGE OF TOTAL MOTHS FOR ALL YEAR FLYING AT VARIOUS HOURS AND PERIODS IN CORN PLOTS, CHATHAM, ONTARIO, 1927–36

Hour of night, Sunset time	Approximate hour of night, Eastern Standard time	Percentage of total moths in flight
−:30	7:30 p.m.	2 3
:30	8:30 p.m.	22.6
1:30	9:30 p.m.	38.4
2:30	10:30 p.m.	18.4
3:30	11:30 p.m.	11.0
4:30	12:30 a.m.	4 3
5:30	1:30 a.m.	1.0
:30 to 4:30	7:30 p.m. to 12:30 a.m.	94.7
:30 to 2:30	8:30 p.m. to 10:30 p.m.	79.4
−:30 to 4:30	7:30 p.m. to 12:30 a.m.	97.0
5:30 to 11:30	1:30 a.m. to 7:30 a.m.	2.7

TABLE 12.—SHOWING TIME OF NIGHT OF MOTH FLIGHT, NUMBER OF MOTHS OBSERVED EACH HOUR OF NIGHT, MALE AND FEMALE COMBINED, CHATHAM, ONTARIO, 1927–36

Year	Hours before or after sunset														
	—:30 minutes	:30 minutes	1:30	2:30	3:30	4:30	5:30	6:30	7:30	8:30	9:30	10:30	11:30	12:30	Totals
1927	*0	465	443	251	195	77	0*	—	—	—	—	—	—	—	1431
1928	3	87	315	135	57	10	0*	3*	7*	3*	0*	—	—	—	620
1929	0	30	51	20	6	1	—	—	—	—	—	—	—	—	108
1930	—	29	85	40	14	1	—	—	—	—	—	—	—	—	169
1931	0	2	55	14	1	0	—	—	—	—	—	—	—	—	72
1932	2	21	105	41	17	10	9	9	2	0	—	—	—	—	216
1933	51	58	87	64	46	29	23	17	9	0	0	2	1	0	387
1934	5	7	14	7	5	3	1	0	—	—	—	—	—	—	42
1935	4	9	15	1	0	0	—	—	—	—	—	—	—	—	29
1936	10	18	64	19	14	6	1	—	—	—	—	—	—	—	132
Totals	75	726	1234	592	355	137	34	29	18	3	0	2	1	0	3206

* Records taken intermittently at this hour this year.

— Means no records taken because one or no moths were caught previous hour.

Flight activity took place at the same hour or period from year to year with remarkable uniformity. In 1933, the flight was greater at – :30 than in any other year. The flight at this hour was made up of a large percentage of males. The year 1933 was also peculiar in that more moths flew at 5:30 and after, than in any other year.

It is quite probable that the method of taking observations until only one or no moths were captured has made some errors in the number caught in the early morning hours of some years, but this must be very small as it will be noticed that when records were not continued the catch in the hours just previous, at 4:30 and 5:30, were extremely small, while in the years when there was a marked early morning flight, the numbers at these hours were quite large and the observations were continued.

The Sexual Differences in Time of Night of Flight

An analysis of the detailed records did not reveal any marked differences in the time of flight of the two sexes. The percentage of males flying at different hours is given in Table 14. The increased percentage of males at – :30 is brought about by the early flight of males in the one year, 1933.

TABLE 14.—PERCENTAGE OF MALES FLYING AT DIFFERENT HOURS AND PERIODS FOR ALL YEARS

Hour of night, Sunset time	Approximate hour of night, Eastern Standard time	Per cent of males in flight
– :30	7:30 p.m.	11.7
:30	8:30 p.m.	9.5
1:30	9:30 p.m.	25.3
2:30	10:30 p.m.	22.4
3:30	11:30 p.m.	18.5
4:30	12:30 a.m.	4.3
– :30 to 4:30	7:30 p.m. to 12:30 a.m.	91.7

A Summary of Time of Night of Flight

From the above, it is seen that moths begin to fly just before sunset and gradually increase in numbers until the period of greatest activity at one and one-half hours past sunset. From this hour on, flight gradually decreases until at four and one-half hours after sunset the moths have largely disappeared from the corn field, although a few are found in some years until eight and one-half or even eleven and one-half hours after sunset. Almost 95% of the moths fly between one-half hour and four and one-half hours after sunset, a period of four hours duration, while 97% fly between – :30 and 4:30 sunset time, a period of four and one-half hours.

Translated into Eastern Standard time, the moths begin to fly in the evening about 7:30 p.m., and continue to increase in numbers until about 9:30 p.m., when the maximum activity takes place. The moths then gradually become fewer in numbers until about 12:30 a.m., when nearly all have left the field, although in some years a few moths fly until as late as 7:30 a.m. This hour is after sunrise. Almost 95% of the moths fly between 8:30 p.m., and 12:30 a.m., and 97% fly between the hours of

7:30 p.m. and 12:30 a.m. Only 2.7% constitute the early morning flight, between the hours of 1:30 a.m., and 7:30 a.m.

The period of activity at Chatham is very close to the periods indicated by other workers. Spencer (26) indicated that the moths did not fly freely until 9:00 p.m., although a few commenced to fly just after dusk. Huber (18) studied the flight and oviposition in Ohio in 1927 and concluded that the peak of activity was about 10:00 p.m., and that 90% of the eggs were laid between 7:00 p.m. and 2:00 a.m., and 48% between 9:00 p.m. and 11:00 p.m. Bottger and Kent (7), in southern Michigan, considered 10:00 p.m. the hour of greatest egg laying and hence, flight activity. Hervey and Palm (17), in 1933, found that moths commenced to fly at dusk but that few were taken in light traps before 10:00 p.m., the majority of catch being made between 10:00 p.m. and midnight with an occasional moth up to 2:00 a.m.

Time of Activity of Nocturnal Insects, with Reference in Particular to that of Lepidoptera

The time of night at which nocturnal insects fly has received very little attention until recently when a small number of investigators, including Seamans and Gray (25), Granovsky (15), and Williams (32), have designed light traps which sort insects according to the periods of night in which they fly. Other authors, however, have contributed to the general fund of knowledge and their findings, including those of the above authors, will be briefly given.

Ainslie (1), as early as 1917, studied the numbers of adult crambids, mostly *Crambus teterrellus* coming to lighted windows throughout the night. Moths were collected at 15-minute intervals. He found that over 41% of the females had flown by 8:30 p.m., and only 3.9% of the males had flown by this hour. Seventy-five per cent of females had flown by 11:45 p.m., but 75% of the males did not fly until 1:45 a.m. Hence, the females flew earlier than the males. He concluded that 60% of the females were collected from dusk until 10:00 p.m.

Ballou (3), in Egypt, in 1916, studied flight of *Platyedra gossypiella* on four nights and found that a great majority flew between 6:00 and 7:00 p.m.

Kaburaki and Kemeto (22), found in Japan that the females of *Chilo simplex* flew mostly an hour or two after sunset, but the males did not predominate until after midnight.

Collins and Nixon (10) caught the greatest numbers of the bud moth, *Eucosma ocellana* Schiff. between 8:30 and 11:30 p.m.

Husain, Khan and Ram (19) studied the flight of *Platyedra gossypiella* in the Punjab. They divided the night into three periods of four hours each. They obtained the maximum flight in the last period at the beginning of their observations and in the early period towards the end during 1929 and 1931, but in 1930 the maximum flight occurred in the middle period for most of the observations. Williams (32), in discussing this paper, states that when temperature was high the maximum flight was always in the last third of the night.

Williams (32) has contributed the most important paper to date upon the times of activity in Lepidoptera. He devised a light trap which divided

the insects into eight groups for each nights' catch. His article is too long for detailed discussion. Briefly, he found that, considering all insects utilized by him, the insects showed a maximum activity in the first and second period of the night and fell to half their numbers in the last period. On good nights for flight, the maximum was not reached until periods two or three, while on poor nights, flight fell rapidly from a maximum in the first period. Lepidoptera in general were found to fly later than Diptera and did not reach maximum activity until periods two to four. The Noctuidae are at maximum at periods four to six and the Geometridae at periods three to five.

A number of species of Lepidoptera are discussed in some detail by Williams (32) and nearly all were found to have an individuality of distribution. One species, *Pterophorus monodactylus* had two maxima during the night in periods two and eight. *Trachea secalis* was shown to have a strikingly different distribution in the two sexes. The females flew earlier than the males. Eighty-one per cent of the Lepidoptera studied appeared to have the same period of maximum flight each of the two years. Williams also found that there is a tendency in many groups for nights with abnormally high catches to have abnormal distributions, usually much later than normal.

In the family, Pyralidae, to which the corn borer belongs, Williams studied five species. These, with their periods of flight maxima, are:

Pyralis costalis, maximum period two and three;

Hapalia lutealis, maximum period seven and eight;

Sylepta ruralis, maximum period six in 1933 and three in 1934;

Loxostege verticalis, maximum period three and four;

Evergestis forficalis, maximum period six or seven.

Granovsky (15) has studied the flight of *Phyllophaga* (Coleoptera) to light during four years at St. Paul, Minnesota. Hourly catches showed that males predominated at lights, that seasonal flight of different species varied considerably and that the sexes fly at different hours of the night.

A Summary of Daily Rhythm of Flight

Most of the studies upon the time of night in which nocturnal insects fly have been made by their capture at light traps. In the present study, actual observations for fifteen minutes each hour of the night within the corn field have been utilized. It was found that corn borer moths begin to fly about one-half hour before sunset, the maximum flight occurring one and one-half hours after sunset. Nearly all flight ceases before four hours after sunset. Williams, as pointed out above, found the maximum period of flight for all Lepidoptera studied by him to be between periods two and four. In July, this would mean between one and one-quarter and four hours after sunset. It would appear, therefore, that the corn borer adults conform to the general period of activity for Lepidoptera in general. Among the Pyralids studied by Williams, *Pyralis costalis* and *Loxostege verticalis* have similar periods of maximum flight activity to the corn borer.

The period of flight during the night was found to be remarkably constant during the ten years.

No sexual distribution of the flight period is found in the corn borer, both sexes flying during the same periods.

The Value of Using Sunset Time

The advantages of using Sunset time have been pointed out earlier in this paper, but might be emphasized at this point. It is extremely satisfying that Williams had recorded his observations in Sunset time as it allows a direct comparison of the times of flights in England and in our own case in Canada without considerable calculations. Meunier (23), in his work on the flight of *Melolontha vulgaris* and Dustan (13), in his work on the Oriental fruit moth, are the only other authors noted to have used Sunset time in their work. It would be a great advantage if it could be used more universally when studying the flight or even other activities of nocturnal insects.

THE FLIGHT TO LIGHT TRAP

Review of Literature on the Flight of the European Corn Borer to Light

Vinal and Caffrey (31) in 1919, are the first American workers to remark upon the phototactic responses of the borer, although Baross, as noted below, in 1904 made observations upon this subject. Vinal and Caffrey report that a light trap, having a yellow light, attracted only seventeen moths in a single night when placed between two fields of early sweet corn in which hundreds of moths were active.

Jablonowski (21) records an observation by L. Baross in Hungary during 1904 in which an acetylene light trap was used. Thirty per cent of the moths captured were those of *Pyrausta nubilalis* Hubn., but the statement does not include the total number of species of other Lepidoptera caught.

Spencer (26), in Ontario during 1921, reports failure to attract moths in any numbers to variously coloured lights.

Caffrey (8) records in 1927 that repeated observations in New England with various types and colours of lights have failed to show that adults are attracted to lights to any extent even though the observations were made where moths were numerous in the fields. Little difference was found in the attraction to stationary or moving white light. In one instance where a trap light was run for 20 consecutive nights in a corn field, only 87 moths were captured; 57 were males and 30 were females. Caffrey (30) records that in experiments with lights of different types, colour and intensities, less than 1% of total moths in the vicinity were captured in any single experiment.

Hervey and Palm (17), in 1935, report the only attempt to control the borer in a corn field by the use of light traps. The work was done at Charlotte, New York State, in 1933. Six light traps of the electrocuter type were put in each of two fields of sweet corn, each a little over one acre in extent. Each trap was fitted with a 75-watt, type A, Mazda lamp. The traps were lighted from 8:15 p.m., until 4:00 a.m., and were in operation

from June 11 to August 8. The catch of moths is shown in Table 15 which is copied from their paper.

TABLE 15.—THE NUMBER AND SEX RATIO OF MOTHS CAPTURED IN LIGHT TRAP, CHARLOTTE, N.Y., 1933. FROM HERVEY AND PALM. PERCENTAGE OF SEXES ADDED BY PRESENT AUTHOR

——	Females, number	Females, per cent	Males, number	Males, per cent	Total catch
Field No. 1	303	57 9	221	42 1	524
Field No. 2	185	55 9	146	44 1	331

As the abundance of larvae was not reduced in the light-trapped fields, the authors concluded that light traps of the type used have little value in controlling the borers in the field and that the response of the borer to the type of light was not strongly positive. They also concluded, as will be discussed below, that the light traps were useful in studying the habits of the insect, particularly the period of flight, flight habits and effect of weather conditions upon the moths.

The percentage of males present in the light trap operated by Hervey and Palm has been calculated and added to the table to show that perhaps the record does not give a true picture of the relative abundance of the sexes in the corn field themselves. As will be noted below, our catches at light traps have been dominated by males, while the catches in the field have been dominated by females except in certain years. It would appear that the presence of the lights in the corn field had attracted more males than otherwise would have been present. It must be stated, however, that Hervey and Palm do not discuss this point in their paper.

Stirrett, Beall and Lindsay (29) discuss in a preliminary way the attraction of the moths to light trap based upon the early work done in the present study.

Bogush (6) discusses in general the value of light traps in the study of insect variations and biology and records that the presence of the corn borer was first discovered in the locality in which he was working in Central Asia by the flight of the moths to light traps.

A Summary of Literature on Flight of Corn Borer Adults to Light

Very few papers deal with this subject. Caffrey gives the best summary and shows that lights of different types, colours or intensities attract less than 1% of the total moths in the vicinity. Hervey and Palm attempted to control the borer in sweet corn fields by attracting moths to light traps, with little success.

The Annual Cycle of Flight According to Light Trap Catches

Figure 3 shows the annual cycle of flight and its variations.

The Seasonal Limits of Flight

A comparison of Figures 2 and 3 shows that the light trap catches record a longer period of flight than do the field captures. The commencement of flight was always earlier in the light trap and the termination of flight was always later. This is shown in Table 16.

TABLE 16.—COMPARISON OF COMMENCEMENT AND TERMINATION OF FLIGHT IN LIGHT TRAP AND IN FIELD, CHATHAM, ONTARIO, 1931–36

Year	Date commencement in field	Date commencement in light trap	Date of termination in field	Date of termination in light trap
1931	June 30	June 26	July 23	Aug. 9
1932	June 28	June 18	July 24	Aug. 11
1933	June 24	June 19	July 20	July 31
1934	June 29	June 20	July 23	Aug. 8
1935	July 5	June 30	July 24	Aug. 11
1936	June 28	June 25	July 24	Aug. 16

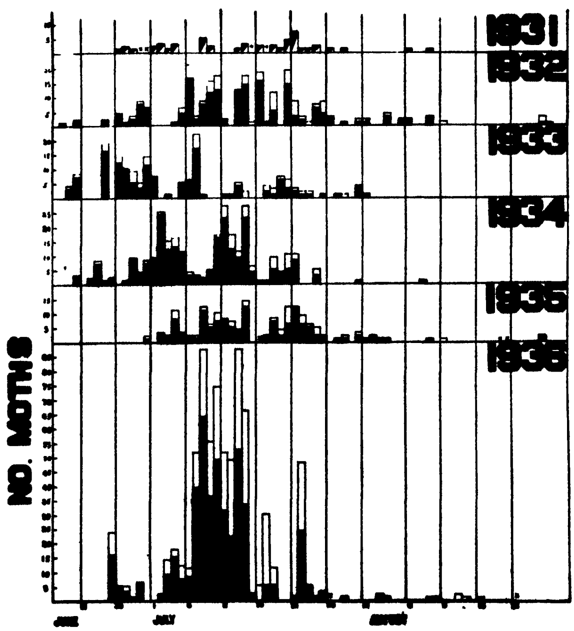

FIGURE 3. Seasonal and daily flight of corn borer moths to light trap, Chatham, Ontario, 1931–36. The black portion of the bar represents the number of females, while the white portion of the bar represents the males captured each night. The sexes were not separated during 1931. The few moths captured very late in the season are not included.

Table 16 shows that moths are attracted to light traps 3 to 10 days earlier than they are to the field. They are also attracted to light traps from 11 to 23 days later than they are to the field. The period in which the bulk of flight takes place does not vary greatly in the field and light

trap catches. Sometimes moths were caught in the light trap months after the regular flight had terminated. These very late catches are not shown in Figure 3, but are presented in Table 17.

TABLE 17.—VERY LATE SEASONAL CAPTURES OF MOTHS IN LIGHT TRAP, CHATHAM, ONTARIO, 1931–36

Year	Date	Number of moths captured
1931	Aug. 31	1
	Sept. 17	1
1932	Aug. 25	3
	Aug. 26	1
1933	—	0
1934	Sept. 1	1
	Oct. 1	1
1935	Aug. 25	2
	Sept. 23	1
1936	Oct. 16	1
	Oct. 26	1

These records constitute the only possible indication that a very small partial second generation of the borer occurs in some years in Ontario. Crawford and Spencer (12) also found indications of a possible very small second brood in 1921 at Port Stanley, Ontario. Bottger and Kent (7) in 1931 found indications of a very small partial second generation in Monroe county, Michigan. From the present records and from those of Crawford and Spencer, it would appear that in Ontario, during the last fifteen years, there has not developed any decided tendency for a second generation to develop.

The Magnitude of Flight

The magnitude of flight for each year and each day can be ascertained from Figure 3. The flight to light traps is also plotted in later figures in Part III, where they are shown in comparison with catches in the field and correlated with the important meteorological factors. In these figures, flight to the light trap is curve "C".

TABLE 18.—SUMMARY OF LIGHT TRAP AND FIELD CATCHES ACCORDING TO SEX AND TOTAL NUMBER OF MOTHS, CHATHAM, ONTARIO, 1931–36

Year	Field catch, Plot "A"				Light trap catch			
	♂	♀	Total	Relative magnitude of flight	♂	♀	Total	Relative magnitude of flight
1931	6	66	72	4	—	—	48	6
1932	30	166	196	2	174	58	232	3
1933	111	224	335	1	135	41	176	4
1934	17	24	41	5	232	43	275	2
1935	6	23	29	6	125	37	162	5
1936	37	94	131	3	455	288	733	1

In Table 18 the number of moths in flight in the field unidentified as to sex has been apportioned according to the sex ratio of the number whose sex was determined. The flight to the light trap was in greater numbers than to the field in each year except 1931 and 1933. As shown by the column "Relative magnitude of flight", there is apparently no relationship between the size of catch in the field and the size of catch in the light trap.

There is apparently no relationship between the numbers of individuals caught each night in the light trap and in the field, although peaks of flight and depressions in flight occur in the light trap catches and in the field on the same days or during the same periods. That no relationship exists between numbers of individuals is shown by the tabulation of light trap catches per night and the field catches per night for the period of moth flight in the field during 1936 (Table 19). A survey of the data for other years indicates that the same condition is true whether total catch or female catch per night is considered.

TABLE 19.—FLIGHT TO LIGHT TRAP AND FLIGHT TO CORN FIELD FOR SAME DATES DURING 1936

Date	Number of moths in corn field, Plot "A"	Number of moths in light trap	Date	Number of moths in corn field, Plot "A"	Number of moths in light trap
June 27	0	5	July 11	18	51
28	1	1	12	6	48
29	0	6	13	11	87
30	0	0	14	6	66
July 1	2	0	15	4	2
2	0	2	16	6	5
3	5	14	27	5	30
4	0	18	18	2	11
5	3	12	19	0	0
6	6	11	20	0	0
7	10	51	21	1	1
8	5	87	22	2	48
9	25	55	23	1	5
10	11	74	24	1	1
			Totals	131	691

This whole question will be discussed later.

Sex Ratio of Moths

The number of male and female moths captured in the light trap is shown in Table 20. They have also been shown in Figure 3. The percentage of males for all years is given in comparison with the percentage found in corn fields.

The years indicated above have a much higher percentage of males in the field than those from 1927 to 1931. The average percentage of males found in the field for ten years is 15.5. The proportion of males in field plot "A" for all years is shown in Table 8. The light trap, therefore, attracts a much larger percentage of males than does corn.

TABLE 20.—NUMBER OF MALES CAPTURED IN FIELD AND LIGHT TRAP, IN PERCENTAGE OF TOTAL CATCH, CHATHAM, ONTAR O, 1932–36

Year	Per cent males in field catch	Per cent males in light trap catch
1932	15.3	75.0
1933	33.2	76.7
1934	41.1	84.3
1935	19.0	77.1
1936	27.2	60 7
Average for period	27.1	74.7

The Attraction of Moths to Corn Field and to Light Trap

The size of the catch of moths taken in the light trap and the size of the catch in the corn field have most of the controlling factors in common and one factor not common. Mutually, they are dependent upon the number of moths in flight in the district and upon meteorological conditions. Respectively, they are dependent upon the attractability of light and corn.

The deficiency of catch in the field early in the season may have occurred because the attractability of the corn was still low and at the end of the season the deficiency may have been caused because the attractability of the corn had diminished. There are other factors, however, that must be considered and which have an influence on the total numbers attracted. In the first place, the light trap was attracting moths over a much longer period of time during the season. It also was in operation during the entire night, whereas the field observations were practically over at 12:30 p.m., in most years because no more moths could be observed. It has been noted that a small flight occurs in the early morning. These moths would be attracted to light and would help swell the light trap total.

There is also a differential in the attraction of the sexes to light and to corn. It has been shown above that the light trap catch consisted on the average of 74.7% males, while that in the field over the same period averaged only 27.1% males, and over a period of ten years averaged only 15.5%. Another factor affecting the size of catch would be the relative range of attractiveness of the light and the corn plot. Nothing is known in this regard.

The Value of Light Traps in the Study of the Biology and Periodicity in Insects

Most of the literature dealing with the operation of light traps is concerned with the value of the traps in the control of some injurious insect, and with these we are not concerned here. There are a few authors, however, who have contributed quantitative data upon the subject under consideration and their work will briefly be reviewed.

Cook (11), in 1928, investigated the questions as to whether or not light traps furnished a reliable index of the relative abundance of a species in the district and from year to year. His work was concerned largely with various species of noctuid moths. He came to the conclusion that there were limits to the use of light traps as indicators of moth population as he found that moths do not come to light in proportion to their abundance as a species within a given year. He also concluded, however, that the catches were reliable for comparisons of flight from year to year.

Caffrey (9) as noted above, states that light traps caught less than 1% of the corn borer moths in the region. Collins and Nixon (10) studied the opposite effect of light, that of retarding or prohibiting flight on *Eucosma ocellana* Schiff. in apple orchards. They obtained a relative value of the abundance of moths in unlighted and lighted trees and found from two to seven times as many in the unlighted trees as in the lighted trees.

Arnott (2) working at Chatham, Ontario, has studied the flight of various species of the genus *Crambus* from light trap catches. Seventeen

species occur in the vicinity of Chatham, two were collected only by the light trap, although extensive field collecting had been in progress for four years. A close relationship is thought to exist between pronounced injury in the field and magnitude of flight as indicated by the trap. Light trap catches showed clearly the flight period, number of broods and fluctuation in numbers from year to year.

. Hervey and Palm (17) conclude that light traps as used by them have a value in studying the habits of the insect, especially in regard to period of flight, flight habits and effect of weather conditions on flight. They state, however, that their traps captured only a small part of the moth population of the field. Granovsky (15) has pointed out that light traps are of service in studying the numerical trends in populations, seasonal occurrence and behaviour under given ecological conditions. Bogush (6) as already noted, has summarized the uses of light traps as follows: in discovering the presence of insects in a region, to help estimate field populations. If oviposition rate is known it is possible to obtain information about survival of different generations and the influence of climatic conditions upon populations and survival.

In the present study, the operation of the light trap was not designed, as pointed out, for direct comparison with field catches. Some conclusions of value can, however, be drawn from the work.

The magnitude of flight from year to year as shown by the light trap and field studies do not agree in total numbers of moths attracted. In fact, it is not possible to make such a comparison.

Males are attracted to the light in larger numbers than are the females, while the females are more strongly attracted to corn than are the males. There is no apparent correlation between the numbers caught in the light trap and those observed in the field on individual nights. The same general trends of flight, peaks of flight, depression of flight are shown in light trap catches and field studies throughout the season. As will be shown later, these are largely controlled by climatic factors.

The light trap is a better measure to determine seasonal limits of flight within the region than is any one individual corn field. The light attracts moths over a longer period each season than does a single corn field.

A very small partial second generation in certain years was discovered through light trap catches.

(To be continued.)

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SCIENTIFIC AGRICULTURE

Vol. XVIII MAY, 1938 No. 9

PRUNING AND FERTILIZATION EXPERIMENTS WITH CONCORD GRAPES

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[Received for publication February 15, 1938]

The grape is one of the important fruit plants grown in the Niagara District of Ontario, and Concord is by far the most important variety. Growers have been seeking advice about practices which might increase the yield and quality of their Concord grapes and up to the present there has been very little data on which to base answers to their questions. Realizing the dearth of information on this subject the Horticultural Experiment Station commenced pruning and fertilization experiments in the spring of 1929 at the Haines vineyard about two miles east of Jordan. At that time the vines in the experimental plots were 5 years of age and in a very good state of vigour.

REVIEW OF LITERATURE

There is a large volume of literature on pruning and fertilizing the Vinifera type of grape but much less on the Labrusca type. As it is very unlikely that results obtained on the former type can be safely applied to the latter only the literature on the Concord variety (Labrusca) will be considered in this paper. Schrader (9, 10), Partridge (6, 7), and Colby and Tucker (1) have considered the physiology of growth and reproduction in this variety. All have emphasized the importance of maintaining a proper balance between growth and fruit production which means a degree of severity of pruning in keeping with the vigour of the vine. Partridge (7) gives a table of the number of buds to leave on each vine at pruning time based on the weight of prunings removed from that vine. Colby and Tucker (1) suggest the use of the presence of lateral (secondary) shoots as an index of the proper degree of pruning, the desired result being the development of some laterals but not enough to make up one-third of the total growth in length of any vine. There is very little information on the effect of pruning of varying degrees of severity on the sugar and acid content of the fruit. In 1934 the authors published a brief note (12) on the effect of overpruning unfertilized vines at the Haines vineyard, results indicating that overpruning reduces the quality as well as the quantity of the fruit.

In Michigan Partridge and Veatch (8) obtained beneficial results from applications of readily available nitrogen and somewhat lesser effects

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from superphosphate and muriate of potash. Increases in crop were obtained largely as a result of increased wood growth, making possible the retention of more buds at pruning time. Recently Gladwin (3) has published a summary of 25 years' fertilization of Concord grapes in New York State which shows an increased yield from an NPK fertilizer, most of the increase appearing to come from the nitrogen and potassium and relatively little or none from the phosphorus even though it did increase the growth of green manure crops. It would seem, however, that the increases in yield from fertilizers in this experiment were not as significant as indicated because the check plot was quite decidedly poorer than most of the treated plots at the beginning of the experiment. Holland (5), using only the NP combination, found an increase in yield of Concord grapes mainly on the lighter soil types of Ohio. Gourley (4) reported the results of another experiment conducted on a heavy type of soil in Ohio. This test showed that the greatest crop increase came from annual applications of eight tons of horse manure per acre, an NPK fertilizer seeming to be of some benefit but nitrogen alone, of doubtful value. On the other hand, in Missouri Faurot (2) found that nitrate of soda increased the yield but phosphate and potash had no effect even though phosphate improved the growth of green manure crops. In this experiment, though farmyard manure increased growth, it decreased the weight of fruit which suggests too severe pruning on these plots. The only straw mulch plot made rampant growth but the fruit yield was low even though 80 to 100 buds were left on these vines. Using the yields from the fifth to the ninth year after annual fertilizations were commenced Stene (11) of the Rhode Island Station, in a comparison with an NPK fertilizer, found that omission of potassium very considerably reduced yields, omission of nitrogen caused a slight reduction and omission of phosphorus was without effect.

From samples taken from the test plots in 1912 Gladwin (3) concludes that the sugar content of the grapes was not affected one way or the other through fertilization. In his experiments, however, nitrogen had a beneficial effect on size of bunch and berry.

EXPERIMENTAL

Soil

The soil at the Haines vineyard is classified as Vineland Clay Loam and is described as moderately acid in reaction, medium in organic matter, replaceable potassium and nitrogen content, for the most part low in readily soluble phosphorus and with heavy poorly drained subsoil. Many of the grape plantings in the Niagara District are situated on this or a similar type of soil. Up to the time of planting to grapes in 1924 this area of land had been used mainly for grain crops and had received very little manure or commercial fertilizers. Until 1929 no commercial fertilizers had been used for the grapes and only a very limited quantity of barnyard manure.

Weather

There was no appreciable freezing or frost damage in this vineyard in the 8-year period, 1929-36, not even after the severe winter of 1933–34. The very high summer temperatures of 1936 played a part in reducing the

crop in that year. However, possibly the most important weather factor concerned was the supply of moisture, and Table 1 is given to illustrate the extremes in summer and yearly precipitation:

Cultural Conditions

The vineyard was cultivated from early spring until about mid-July as often as it was neecssary to keep down weed growth. No green manure crops were sown except on 3 plots which were used for comparison, and the weed growth developing after the last cultivation was often very meagre. The pruning and harvesting were done by the Experiment Station. The only spray applied regularly was a Bordeaux-nicotine spray just after the fruit had set.

TABLE 1.—TOTAL PRECIPITATION

—	Whole Year	Summer months (June-Sept. incl.)
1929	31 0	8.4
1930	24.0	7.8
1931	30.0	11 3
1932	38 2	12.7
1933	29.7	9.9
1934	24.5	9.9
1935	24 0	6.5
1936	28.4	9.1
21-year mean	28.8	10.8

Plan of Experiment

In Figure 1 the arrangement of series and plots and the treatments are shown. Every third plot is untreated and is used to measure the increase or decrease due to treatment of the adjacent plots. The "normal" of a treated plot was obtained from the formula, $\frac{2}{3}C^1 + \frac{1}{3}C^2$ where C^1 is the nearer untreated plot and C^2, the more distant. As may be seen later in this report the soil did not change in a uniform manner but presented a patchy condition and to this extent the method of analysis fell short; however, by referring to the first year's figures due allowance can be made for this inadequacy.

Shortly after the shoot buds had burst fertilizers were applied on the surface and disked in immediately. They were applied only as far as the end vine of each plot, leaving a buffer area of 9 feet between plots. This is probably insufficient to protect against the dragging of fertilizer from one plot to another but the amount of fertilizer getting into the next plot would be comparatively small. In any case it seemed to the authors that, because of the reduction in the number of vines per plot by the omission of the end vines, there would be less error through their inclusion. However, as the sample of fruit taken for analysis was sufficiently large without them no bunches were taken from the end vines of each plot.

Fertilizer applications were commenced on A, B and C Series in the spring of 1929 and on D series in 1930. Straw was first applied in the fall of 1930 and seed was first sown on the green manure plots in the summer of 1931. Millet was used for 3 years and buckwheat, for one year. In 1935 and 1936, because of dry conditions, summer crops failed and fall rye was sown.

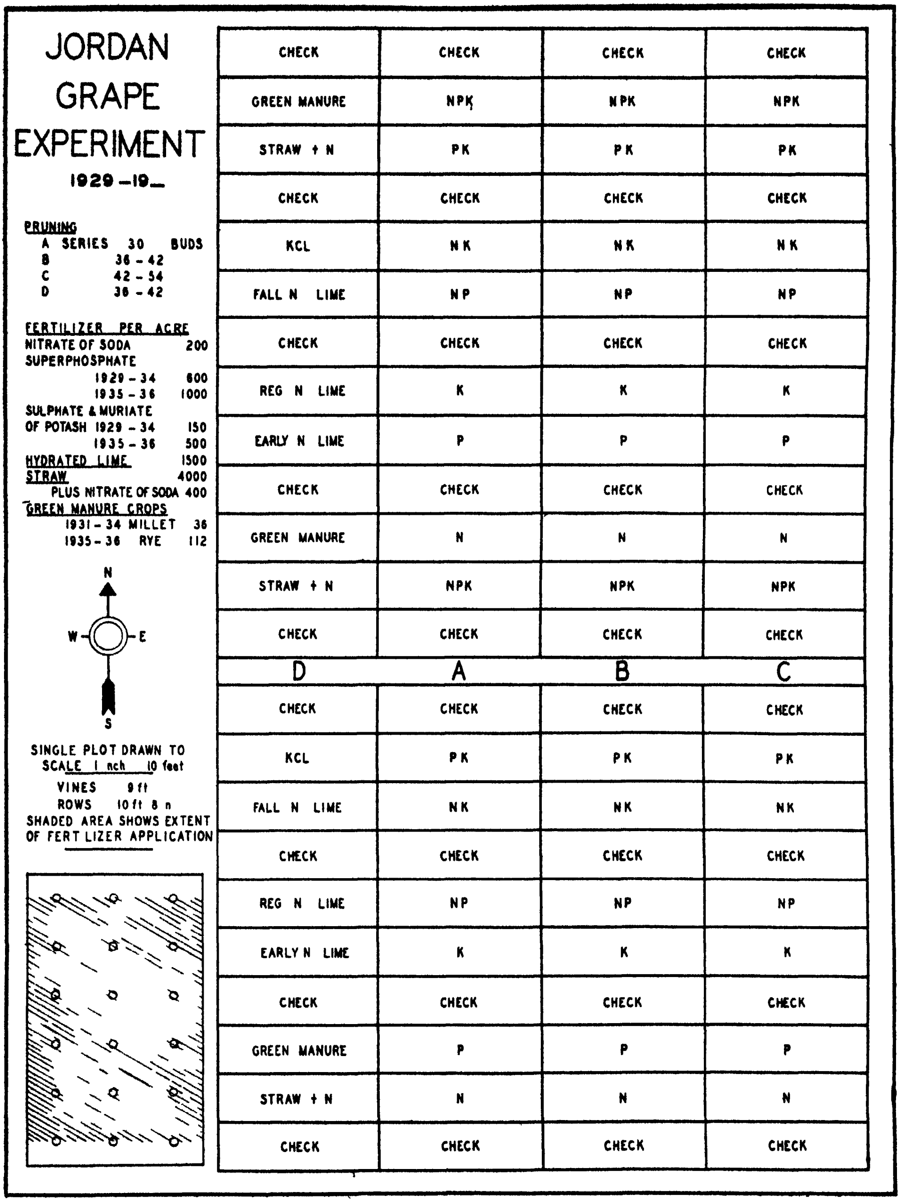

FIGURE 1. Arrangement of series and plots giving treatments of each.

Methods

Individual vine yield records were taken Where vines were missing, small as a result of later planting, or damaged from Dead Arm disease, the average yield of the other vines of the plot was substituted As such vines were less than 5% of the total number under experimentation the error was not very great. For weight of prunings the plot was the unit used, the

labour required to obtain individual vine records being too great in such an extensive experiment. Samples of fruit were taken for sugar and acid analysis 2 weeks and again 3 days before cutting the crop. The samples were kept in a cool cellar and analysis was always completed within 60 hours. Berries were picked from the bunches and a uniform volume was squeezed in a Carver laboratory press at 4,000 lbs. pressure. Sugar determinations were made by a method given in Sutton's Volumetric Analysis (10th ed., page 331). This proved to be a rapid and sufficiently accurate method. Total acid was obtained by the Official Method. As only a hand press, which did not give uniform squeezing, was available in 1929 the sugar and acid readings for this year are not included in this paper.

RESULTS

1. Effects of Heavy, Moderate and Light Pruning on Wood Growth, Yield and Quality of Fruit

The relation between wood growth and fruit production is well illustrated in Table 2. A Series has very definitely been overpruned with a resulting strong wood growth made at the expense of the fruit crop. B Series has probably also been overpruned though to a lesser degree. C Series was pruned to 42 buds per vine up until 1934 but in 1934, 1935 and 1936 the number of buds left was 54 which meant an underpruning for some plots though not for others. However, some of the weaker growing plots were showing definite signs of distress in 1935 and 1936. In Plot C10, the poorest in the experiment, vines were beginning to die out. The yield figures show average crops of over 4 tons per acre on B and C Series which is well above the average for the district. It is evident, however, that the vineyard has been failing to a certain extent to withstand the drouth conditions in the summers of 1935 and 1936.

TABLE 2.—EFFECTS OF HEAVY, MODERATE AND LIGHT PRUNING ON WOOD GROWTH, YIELD AND QUALITY OF FRUIT

Series	A	B	C
Number of buds left	30	36–42	42–54
Weight of prunings per acre per year (1932–37) lbs.	1625	1422	1208
Yield per acre per year (1929–36) lbs.	7385	8439	8998
Per cent sugar per year (1930–36)	15.6	15.0	14.9
Per cent total acid per year (1930–36)	.69	.67	.66

Some overpruning results in a slight increase in sugar content of the grape juice but carried to an extreme, as it was on some of the stronger growing plots of A and B Series, sugar content was reduced as has been noted in a previous paper by the authors (12). Considering all the plots in A, B and C Series there has been no appreciable pruning effect on total acids in the grape juice but considering only the extremely vegetative plots, total acids were always higher than the average. Judging from sugar and acid content of the juice there is no reason for deliberate overpruning to improve eating quality particularly when quantity of fruit is thereby reduced.

There is the companion question as to whether underpruning adversely affects quality. Up to 1934 there were no plots in the experiment which were definitely undervegetative as a result of underpruning but the authors supposed (12) that this condition would result in low sugar and high acid content of the juice. Having, from 1934 on, increased the number of buds left on C Series from 42 to 54 per vine some of the poorer plots became definitely undervegetative. To learn that the sugar content of the juice from these plots was slightly higher than the average for all plots and the total acids were somewhat lower was quite surprising. However, the berries were small and the bunches small and loose. A comparison of the 1936 fruit of two unfertilized plots, C7 and C10, not far removed from one another, but showing contrasting growth conditions is illustrated in Figure 2. It is quite apparent that underpruning reduced the quality of the fruit as measured by bunch and berry but not as measured by sugar and acid content of the juice.

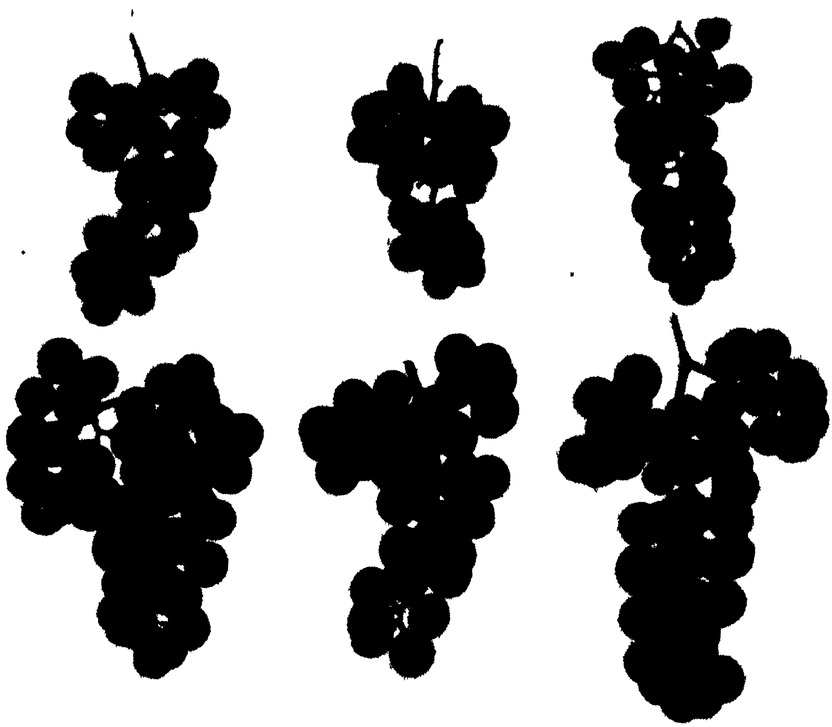

FIGURE 2. Upper row:— 3 typical bunches of the 1936 crop from Plot C10—a very weakly vegetative plot having an average of 1 1 lbs. of prunings per vine in January 1936. Sugar and acid content of the juice from this plot in 1936 were 18 2 and 0 58% respectively. Lower row:— 3 typical bunches of the 1936 crop from Plot C7—a strongly vegetative plot having an average of 3.4 lbs. of prunings per vine in January. 1936. Sugar and acid content of the juice from this plot in 1936 were17 0 and 0 69% respectively. Being in the same series the same number of buds per vine had been left at pruning time on each of these plots (54 in 1936).

2. Effect of Applications of Nitrogen, Phosphorus, and Potassium on Wood Growth, Yield, and Quality of Fruit

Wood Growth

TABLE 3.—EFFECT OF FERTILIZERS ON WEIGHT OF PRUNINGS*

—	N	P	K	NP	NK	PK	NPK
1929†	− 2.2	+10.9	+ 3.5	+ 6.6	− 5.0	+ 2.6	− 8.4
1932	−13.3	− 6.3	+ 3.1	+ 4.6	+ 1.4	−10.1	− 0.6
1933	− 8.6	+ 2.9	+ 2.3	+ 6.6	+ 9.5	− 2.2	+ 4.9
1934	− 8.4	+ 2.8	+ 6.8	+ 5.1	+ 2.5	− 7.2	+ 5.5
1935	−10.3	+10.4	+10.7	+20.7	+ 3.7	+ 3.8	+21.9
1936	− 8.9	+10.5	+ 8.2	+16.4	+ 7.7	− 6.4	+16.4
1937	−18.1	+ 1.9	+ 4.8	+18.7	+ 1.7	− 0.2	+17.1

* Each figure represents the mean percentage increase or decrease of six treated plots from their adjacent untreated plots (A, B and C Series). Figures given for a certain year refer to the growth of the preceding year. In 1930 and 1931 pruning weights were not taken.
† No treatment at this time.

Using 1929 figures as a base the following conclusions seem justified. 1. Nitrate of soda has decreased growth to a slight extent. 2. Superphosphate alone and sulphate of potash alone have not increased growth. 3. All combinations containing nitrate of soda seem to have increased growth to a slight extent, the NPK combination being most useful. 4. The phosphate-potash combination has been ineffective.

On all phosphate plots weed growth has been stimulated, which is an indication that phosphate might be applied to advantage to increase the growth of green manure crops.

Yield

TABLE 4.—EFFECT OF FERTILIZERS ON YIELD OF FRUIT*

—	N	P	K	NP	NK	PK	NPK
1929	−1.7	+ 4.8	+3 5	+ 1.9	+ 3.6	− 1.1	+ 0.5
1930	−3.0	+ 0.2	−1 5	+ 5.2	+ 3.3	+ 3.2	− 0.4
1931	−0.4	+ 3.2	+2 4	− 0.9	+ 6.9	+ 3.0	+ 4.7
1932	−0.8	+ 2 3	+6 2	+ 2.4	+ 6.0	+ 1.3	+ 1.8
1933	+1.2	+ 4.8	+7.5	+ 5.1	+10.1	+ 8.6	+ 8.4
1934	−5.3	+ 5.2	+3.4	− 0.7	+ 5.9	+ 7.9	+ 8.2
1935	+2.9	+10.0	+3.1	+ 5.3	+ 8.0	+11.4	+ 5.2
1936	−7.8	+ 3.1	+5.9	+11.2	+12.3	+ 7.1	+10.5

* Each figure represents the mean percentage increase or decrease of six treated plots from their adjacent untreated plots (A, B and C Series).

In a general way the comparative yields of fruit from the various treatments present a close parallel to the wood growth (Table 2). In 1936, the greatest increase in yield of fruit, which resulted from the NPK treatment, was 10%. At prevailing prices of fertilizer and grapes 10% increase in crop is not nearly enough to pay for the fertilizer and its application in the amounts noted in Figure 1. However, knowing that the soil is very low in readily available phosphorus and approaching a deficiency in replaceable potassium, one would expect that the effect of fertilization would last for many years and thus show a profit eventually.

Quality of Fruit

TABLE 5.—EFFECT OF FERTILIZERS ON PERCENTAGE SUGAR IN THE JUICE*

—	N	P	K	NP	NK	PK	NPK
1930	+1.0	−1.3	−4.3	−4.8	−1.3	−6.2	+2.8
1931	+1.1	+2.5	−1.6	−2.4	+1.3	−0.7	+3.7
1932	+2.2	+2.6	+1.4	+0.2	+2.7	+2.8	0
1933	+2.2	+1.2	−1.2	−1.5	+0.8	+0.3	−1.7
1934	+0.4	+0.1	−1.3	−1.0	+0.4	+3.3	+0.4
1935	−1.5	−0.2	−0.9	−0.8	+0.7	+1.1	+0.7
1936	+0.5	+0.8	−2.2	−3.4	+0.5	+0.2	−1.4

* Each figure represents the mean percentage increase or decrease of 6 treated plots from their adjacent check plots (A, B and C Series). Two samples were taken from each plot at intervals of about 11 days.

TABLE 6.—EFFECT OF FERTILIZERS ON PERCENTAGE TOTAL ACIDS IN THE JUICE*

—	N	P	K	NP	NK	PK	NPK
1930	−1.9	+1.6	+0.8	−0.6	−1.1	+0.2	−2.3
1931	−1.0	−0.7	+0.2	+0.6	+0.5	−0.3	−0.5
1932	−5.1	−3.8	+3.8	+3.8	−0.2	−0.7	−1.2
1933	−3.1	+2.1	+4.5	+2.3	+0.9	−3.0	+1.6
1934	−2.0	+3.1	+4.3	+4.5	+2 2	+1.7	+1.2
1935	−2.6	+4.3	+4.0	+5.4	+0.4	+1.7	+2.9
1936	−3.1	+1.8	+7.7	+4.5	−0.2	+1.7	−0.7

* Each figure represents the mean percentage increase or decrease of six treated plots from their adjacent check plots (A, B and C Series). Two samples were taken from each plot at intervals of about 11 days.

From an examination of Tables 5 and 6 it is obvious that if any fertilizer has had an effect on the sugar and acid content of the juice it has been a very minor one and of no commercial importance. This result is in accord with the findings of Gladwin (3).

Effect of Applications of Straw and Lime, and the Growing of Green Manure Crops on Wood Growth, Yield, and Quality of Fruit

Wood Growth

TABLE 7.—EFFECT OF VARIOUS SOIL TREATMENTS ON WEIGHT OF PRUNINGS*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-October	Muriate of potash
1931	− 1.3†	−14.9†	+12.0	+16.7	−3.8†	+6.3
1933	+15.2	+ 7.1	+ 6.3	+11.4	+2.3	−4.9
1934	+31.3	+ 9.4	+ 7.6	+16.7	+5.0	+3.4
1935	+38.6	+20.2	+21.6	+15.8	+2.7	+4.6
1936	+37.7	+22.6	+17.7‡	+20.9‡	+4.6‡	+4.2
1937	+30.9	− 9.5	+33.3	+14.5	+6.1	+4.8

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check plots (D series). In 1932 pruning weights were not recorded.
† No treatment at this time.
‡ Limed—no nitrogen added after 1935.

As in A, B and C Series there was no increased growth from applications of nitrate of soda, but in contrast there seemed to be no decrease in growth in D series. There seemed to be no object in continuing to use nitrogen in D series, and as many growers are using lime or a lime-carrying fertilizer it seemed wise to change the nitrogen plots to lime plots; therefore in the spring of 1935 hydrated lime was applied to these 6 plots at the rate of 1500 lbs. per acre. Up to the present no more lime has been applied to these plots. At the present time there appears to be no appreciable effect from lime either one way or the other. As with sulphate of potash alone on A, B and C Series, muriate of potash alone (D Series) appears to have been ineffective.

By far the most marked response from any treatment in this experiment is that resulting from additions of organic matter. Straw plus nitrate has given the greatest growth increase but green manure crops have been a close second. Even though the growth of green manure crops, mostly Japanese Millet, has been rather poor, averaging about 15 inches in height, the response in vine growth has been considerable. The falling-off in 1936 growth (1937 prunings) was probably due entirely to the rye crop being left standing too long.

Yield

TABLE 8.—EFFECT OF VARIOUS SOIL TREATMENTS ON YIELD OF FRUIT*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-Oct.	Muriate of potash
1930	+ 3.2†	− 9 5†	+ 6 7	+ 4.5	+5.4†	+ 5.7
1931	+ 0.4	− 3.3	− 1 4	− 1.6	+6.1	− 3.8
1932	+12.4	+ 1.1	+ 2 0	+ 2.8	+9.8	+12.2
1933	+ 5.7	+ 2.9	+ 5.1	+ 5.5	+9.7	+ 0.3
1934	+13 8	+ 1.1	− 0.5	+ 1.6	−3.0	+ 8.1
1935	+16 5	+ 6.6	+13.4‡	+ 7.2‡	+6.5‡	+11.3
1936	+24.3	+ 1 3	+ 8.0	+11 8	+2.8	+ 6.4

* Each figure represents the mean percentagei ncrease or decrease of two or three treated plots from their adjacent check lots (D series).
† No treatment at this time.
‡ Limed—no nitrogen added after 1934.

Effects of the various treatments in D series on yield of fruit (Table 8) are very similar to the effects on wood growth (Table 7) but of slightly lower proportions, *i.e.*, fruit production has not quite kept up with growth increases even though, beginning in 1935, D series has been pruned according to vigour using Partridge's recommendations (6). Although no straw has been applied since the fall of 1934 the straw plots have continued to show larger yield increases. The drop in relative yield from the green manure plots in 1936 can almost be attributed to the rye crop being left standing too long. Up to the present time it is doubtful if the straw plus nitrogen has been a profitable practice but if these plots continue to produce heavier crops than the check plots, without further additions of straw and nitrogen, a profit will be realized. The green manure crops have been profitable as the cost of seed and seeding has been small. Lime applied in the spring of 1935 has had no appreciable effect on the 1935 and 1936 crops, and muriate of potash, like sulphate of potash in A, B and C series, has not increased yields when used alone.

Quality of Fruit

TABLE 9.—EFFECT OF VARIOUS SOIL TREATMENTS ON PERCENTAGE SUGAR IN THE JUICE*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-Oct.	Muriate of potash
1930			+0.7	+0.5		+0.7
1931	−5.1	−1.9	+0.6	−9.8	+2.3	−3.1
1932	−2.7	+0.4	−2.1	−2.5	−1.7	−0.5
1933	−4.2	−2.0	−2.3	−0.9	−0 8	−0.5
1934	−3.0	+0.2	+0.5	+1.0	+1.4	+4.0
1935	−6.1	−3.2	−5.9†	−3.2†	−4.6†	−0.9
1936	−3.0	+0.4	−1.1	−2.0	+0.5	+1.3

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check plots (D Series). Two samples were taken from each plot at intervals of about 11 days.
† Limed—no nitrogen added after 1935.

TABLE 10.—EFFECT OF VARIOUS SOIL TREATMENTS ON PERCENTAGE TOTAL ACIDS IN THE JUICE*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-Oct.	Muriate of potash
1930			− 0.2	+4.0		+5.9
1931	+3.4	+0.4	+ 2.0	+1.6	−0 9	+1.5
1932	+8.1	+2.8	+ 4.8	+9.3	+0 8	+2.5
1933	+7.8	+6.5	+ 5.4	+8 8	+4 1	−0 5
1934	+5.0	+7.7	+ 5.5	+4.2	+0 9	+1.8
1935	+6.1	+4.8	+13.4†	+6.1†	+7.1†	+4 7
1936	−0.8	+1.9	+ 4.1	+2 7	+0.8	+6.0

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check plots (D series). Two samples were taken from each plot at intervals of about 11 days.
† Limed—no nitrogen added after 1935.

A survey of the results given in Tables 9 and 10 shows no consistent or significant effects of added organic matter, lime, nitrate of soda or muriate of potash on the quality of the fruit as measured by sugar and acid content.

Changes in Sugar and Acid Content of the Juice in the Final Stages of Ripening

In taking two samples from each plot each year at an average interval of 11 days an excellent opportunity was afforded to measure the changes in sugar and acid content of the juice as ripening progressed. It is known that grapes improve in taste up to the normal cutting season and the average person considers that this improvement is due mainly to increased sugar content. Our results, 1930–36, indicate that there is much greater improvement in quality by means of reduction in total acid content as the following figures show.

	First test	Second Test (11 days later)	
Mean percentage sugar	14.7	15.5	= 5 4% increase
Mean percentage total acids	.74	.61	= 17.6% decrease

Effects on the Soil of Applications of Fertilizers, Lime, and Organic Matter

Soil samples were taken from each plot in A, B and C Series in the spring of 1929, spring of 1934 and in the fall of 1936. Samples from D Series were taken in 1930 instead of 1929. Each surface sample was a composite of 6 equally distributed borings and each subsurface sample, 4 borings. On the average surface samples were from the top 6 inches and subsurface samples, from the second 6 inches. Unfortunately a number of the 1930 samples of D Series were ruined for analytical purposes. 1934 samples were used only for phosphorus tests.

Readily Available Phosphorus

TABLE 11.—READILY AVAILABLE PHOSPHORUS (P.P.M.) $KHSO_4$ METHOD. MEANS OF 6 PLOTS IN A, B AND C SERIES*

Treatment	Surface			Subsurface		
	1929 spring	1934 spring	1936 fall	1929 spring	1934 spring	1936 fall
N	39	47	49	27	30	35
P	**33**	86	**80**	**30**	37	**54**
K	28	35	38	21	35	27
NP	**29**	64	**89**	33	27	37
NK	26	36	41	28	26	28
PK	**19**	69	**62**	34	24	33
NPK	**28**	66	**87**	27	18	33
Untreated (27 plots)	32	39	45	37	29	32

* 1929 and 1936 figures of a given treatment in boldface type represent significant differences (Student's method).

Over the 8-year period a total of 5600 lbs. per acre of superphosphate, alone and in combination, was applied. It is very evident that these amounts have significantly increased the readily available phosphorus in the surface soil, but the increase in the subsurface soil has been insignificant except where superphosphate was used alone. It is a well known fact that phosphates tend to remain in the top soil, and therefore it is not surprising that the subsurface soil shows little increase. As cultivation and drouth conditions tend to discourage root growth in the top soil it is quite possible that the grape roots may still be more or less starved for phosphorus as the figures for the subsurface soil represent a low level of phosphorus. Below 40 p.p.m. is considered insufficient for grain crops but the line between deficiency and sufficiency for the grape is not known. No explanation can be offered for the increase of readily available phosphorus in the surface soil and decrease in the subsurface soil of the untreated plots.

While the number of samples is scarcely enough to yield definite conclusions one is probably justified in saying that added organic matter, lime and muriate of potash have not materially altered the supply of readily available phosphorus (Table 12) except for the decrease in the subsurface samples from the muriate of potash plots. This marked decrease cannot be explained. That hydrated lime applied in the spring of 1935 has had no effect one way or the other is of particular interest.

TABLE 12.—READILY AVAILABLE PHOSPHORUS (P.P.M.) $KHSO_4$ METHOD. D SERIES

Treatment	No. of plots	Surface		Subsurface	
		1934 spring	1936 fall	1934 spring	1936 fall
Straw + N	3	51	43	46	34
Green manure	3	43	49	41	37
Lime	6	40	41	37	33
Muriate of potash	2	30	28	41	21
Untreated	9	42	42	41	36

Replaceable Potassium

TABLE 13.—REPLACEABLE POTASSIUM (P.P.M.).* MEANS OF 6 PLOTS IN A, B AND C SERIES†

Treatment	Surface		Subsurface	
	1929 spring	1936 fall	1929 spring	1936 fall
N	88	140	94	105
P	111	150	104	137
K	**92**	**240**	82	116
NP	85	111	88	90
NK	**94**	**250**	99	127
PK	**89**	241	96	127
NPK	**78**	**289**	111	136
Untreated (27 plots)	**98**	**135**	97	120

* Truog's modification of the sodium cobaltinitrite method.
† 1929 and 1936 figures of a given treatment in boldface type represent significant differences (Student's method).

For the grain crops about 80 p.p.m. of replaceable potassium is considered the line between deficiency and sufficiency. The potassium needs of the grape are unknown. However, it is evident (Table 13) that some of this area might show a response to potassium fertilization of green manure (grain) crops, though phosphorus appears to be the more deficient of these two elements.

Over the 8-year period a total of 1900 lbs. per acre of sulphate of potash has been applied to the potassium plots. This application has resulted in a very significant increase in replaceable potassium in the surface soil but not in the subsurface soil (Table 13). Increases in the latter are only slightly greater than the increases in the untreated plots; therefore it is very doubtful if any of the applied potassium has reached the subsurface soil. As it is well known that ordinary potassium fertilizers tend to become fixed in the surface soil or at least move slowly to lower levels, this result was not unexpected. No explanation can be offered for the increase of replâceable potassium in the surface and subsurface soils of the unfertilized plots.

Because of the loss of a number of the 1930 samples from D Series there are not sufficient comparisons to warrant conclusions concerning the

effect of the treatments on replaceable potassium, though an effect without significance is indicated except where muriate of potash was applied.

Lime

All of the 1929 and 1930 soil samples were tested for pH, using the quinhydrome electrode. The average pH of the surface soil was 5.51, and of the subsurface soil, 5.84, both generally considered medium acid. A few of the 1936 samples which were tested showed a slight decrease in acidity in the surface soil but no change in subsurface soil. The addition of 1500 lbs. of hydrated lime per acre in the spring of 1934 to six plots in D Series changed the soil reaction to a considerable extent but did not bring the soils to the neutral point. The pH values, means of the 6 lime plots, were as follows:

	Surface	Subsurface
1930	5.86	5.91
1936	6.59	6.20

The 1936 samples from D Series were tested for replaceable calcium, ($KMnO_4$ Method). An average of the readings from all 9 checks was 2013 p.p.m. for surface soil, and 2105 p.p.m. for subsurface soil—a fairly high level for this element. Additions of organic materials and muriate of potash have not appreciably altered the amounts of replaceable calcium and even the 1500 lb. application of hydrated lime has been without effect in changing this level.

Organic Matter

A few of the 1936 samples taken from D Series were tested for organic matter content using Schollenberger's Chromic Acid Method. For surface soils only, the average percentage organic matter was as follows—

6 untreated plots	3.81%
3 straw—N plots	4 40%
3 green manure plots	3.94%

The difference between untreated and green manure plots cannot be considered significant, and the addition of two tons of straw per acre per year for 5 consecutive years has but slightly increased the organic matter content of these plots as measured by the Chromic Acid Method.

DISCUSSION

In this experiment there has been a wide range of vigour in the various plots, and yet the sugar and acid content of the juice of the grapes has not varied sufficiently to warrant the adoption of unusual pruning practices. Apparently the wine and juice manufacturers cannot expect much improvement in the sugar and acid content of the grape juice by alterations in the vigour of the vines. It has been shown, however, that the state of vigour of the vine does affect size of bunch and berry and it may also affect the yield of juice per ton of grapes, a point which our data does not touch. The desirability of a satisfactory balance between growth and fruit production has again been demonstrated. Overpruning results in rampant growth made at the expense of the fruit crop, and underpruning with con-

sequent overbearing results in weak vines very subject to damage from drouth or freezing. In this vineyard a desirable state of vigour seems to be such as will yield from two to three pounds of prunings per vine calling for the retention at pruning time of from 38 to 48 buds.

The failure of nitrate of soda to stimulate growth or fruit production in this vineyard is rather an unusual result for this fertilizer. Evidently nitrogen is not the major limiting factor. Judging by the low level of readily available phosphorus this element may be *the* limiting factor, but not knowing the desirable level of phosphorus for the grape there can be no certainty that this is the case. There is some evidence from foliage symptoms that potassium may be a limiting factor in certain areas. While the analyses indicate that the potassium is not as likely to be a limiting factor as the phosphorus there are some areas which were quite low in replaceable potassium.

Very limited observations indicate that the bulk of the roots are in the subsurface soil, and analyses show that very little of the phosphate and potash applied on the surface and disked in has reached this level. However, the increase in growth and fruiting when phosphate and potash are added to the nitrate indicates some beneficial effect, direct or indirect, from these nutrients. As these effects have been small and slow to appear, and as it has been shown that superphosphate and sulphate or muriate of potash remain largely in the top soil, deep placement of these fertilizers should be tried.

The favourable results from the use of straw plus nitrate and from summer green manure crops are worthy of note. It is probable that an equivalent application of barnyard manure would have given as good or better results than the straw plus nitrate, and it is conceivable that there would be additional advantage from green manure crops if properly fertilized. As weedgrowth has been stimulated by phosphate applications, and as additions of organic materials have had a beneficial effect, the use of phosphate fertilizers with green manure crops would seem advisable.

Because of the favourable response from organic additions to the soil the experiment was altered in 1937 to make the major comparions between alfalfa hay with fertilizers, alfalfa hay without fertilizers, and fertilizers alone, the alfalfa hay being applied in the fall in a finely cut form and ploughed in at once.

CONCLUSIONS

1. Overpruning caused crop reduction but there was some compensation in larger bunches and berries, and, if not carried to an extreme, a slight increase in sugar content of the juice. Extreme overpruning resulted in lower sugar and higher acid in the juice. Underpruning gave small bunches and small berries but the fruit ripened at normal time as measured by the sugar and acid content of the juice. Eventually underpruning resulted in weak vines very subject to injury from drouth and freezing.

2. Improvement in eating quality of the grape during the last few days before cutting time was effected much more by a reduction of acid content than by an increase in sugar content.

3. The soil in this vineyard was found to be very low in readily available phosphorus, low to medium in replaceable potassium, fairly high in replaceable calcium but medium acid in reaction, and medium in organic matter.

4. In this experiment no fertilizer had any appreciable influence on the sugar and acid content of the grape juice. This does not prove, however, that phosphate and potash are without effect since soil analyses have shown that a large part of these fertilizers have remained above the root zone.

5. Nitrate of soda alone was ineffective in increasing growth or fruitfulness and in fact there was a slight depression of growth and fruiting. The increases in yield from the various fertilizer combinations were very small, the combination of nitrate, phosphate and potash giving the greatest response.

6. Additions of organic materials, straw and green manure crops, without phosphate and potash have given marked increases in growth and fruit production.

7. Very little, if any, phosphate and potash applied on the surface has penetrated below the top 6 inches of soil. Limited observations indicate that very few of the roots are to be found in the surface soil therefore the roots may have had very little access to the added minerals.

ACKNOWLEDGMENT

The writers wish to acknowledge the assistance of the Department of Chemistry of the Ontario Agricultural College, in particular the co-operation of Prof. G. N. Ruhnke and Mr. N. J. Thomas. Our thanks are due also to Prof. E. F. Palmer, Director of this Station, for suggestions on the conduct of the experiment and for reviewing the manuscript; to Mr. C. S. Shaw who did a large part of the soil analysis, and to other members of the Staff of this Station who assisted us from time to time.

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VARIETAL RESISTANCE OF WHEAT AND OATS TO ROOT ROT CAUSED BY *FUSARIUM CULMORUM* AND *HELMINTHOSPORIUM SATIVUM*[1]

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[Received for publication January 31, 1938]

INTRODUCTION

The problem of root rot of wheat and other small grains is one of considerable complexity, because several fungi may be involved as causal organisms, alone or in association, and each may be affected by soil, climate, and other factors. The production of resistant varieties would appear to be the most satisfactory method of controlling this important disease of cereals. However, before any particular advance can be made by the plant breeder towards developing varieties that are resistant to root rot, some satisfactory field method has to be found for selecting parental material and testing standard and new varieties. The object of the present investigation was threefold: (1) to develop an accurate method for measuring the amount of disease caused by root-rotting fungi on cereals, (2) to devise practical and efficient methods for producing under field conditions positive attacks of common root rot, and (3) to determine the relative susceptibility of standard varieties and new rust-resistant strains of wheat already produced to *Fusarium culmorum* (W.G.Sm.) Sacc. and *Helminthosporium sativum* P.K. & B., and similarly of oats to *Fusarium culmorum.* The investigation was begun at the Dominion Rust Research Laboratory, Winnipeg, Manitoba, in 1930. Brief reports on the progress of the work have already appeared (3, 4). The purpose of this paper is to summarize the results of field experiments made during the 7-year period 1930 to 1936.

In this paper the descriptive name "root rot" is used to indicate a diseased condition of the base and roots of cereal plants caused by *F. culmorum*, *H. sativum*, and some other fungi. This disease is manifested variously by such symptoms as pre-emergence killing, seedling blight, basal browning, crown rot, foot rot, and root rot. It is widely distributed in the three prairie provinces of Canada, and frequently it is a limiting factor in the production of cereal crops (1). Owing to the extensive scale on which wheat is grown in these provinces, the greatest economic loss from common root rot occurs in this crop.

Before presenting the results with which this paper is mainly concerned, mention should be made of some preliminary experiments made at Winnipeg in 1930 and 1931. In each of these two years 3 field experiments were made to compare the reactions of 40 varieties of wheat, 12 of oat, and 11 of barley to *Fusarium culmorum*, to *Helminthosporium sativum*, and to a miscellaneous group of soil fungi that included these two. The system of replication used in each experiment was 3 randomised blocks of 63 plots each. The seed was inoculated with spores of the fungus or fungi against

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which the varieties were to be tested, and spores and mycelial fragments of the fungus or fungi were added to the soil. Disease and yield data were recorded for each plot, and the data of each experiment were analyzed by the analysis of variance method suggested by Fisher (2).

No significant differences in the degree of resistance to *F. culmorum*, to *H. sativum*, or to the mixed group of fungi were established between varieties in these 2 years. All varieties and selections of wheat tested gave fairly high disease-infection ratings. The variety Mindum and a few selections with Mindum parentage seemed to be slightly more susceptible than the others. No appreciable differences in susceptibility were observed among the oat or the barley varieties.

EXPERIMENTAL METHODS

The results of the preliminary experiments of 1930 and 1931 emphasized a distinct need for more information concerning methods of infesting field plots with cereal root-rot fungi, and led, in 1932, to the establishment of a series of large, permanent, artificially-infested plots (Root-Rot Garden) at Winnipeg, Manitoba. From 1932 to 1935 these plots were used to study the comparative susceptibility of wheat varieties to fungi most commonly associated with root rot in Manitoba. In addition, extensive varietal trials, both with wheat and oats, were made at different stations in Manitoba in 1934, 1935, and 1936.

Root-Rot Garden Tests

The system of replication used in the root-rot garden was 6 randomised blocks of 4 large plots each. In 1932, and in each of the 3 succeeding years, each of the 4 plots received a different treatment, but in all 4 years a plot received the same treatment. The treatments were as follows: (1) soil and seed artificially infested with *F. culmorum*; (2) soil and seed artificially infested with *H. sativum*; (3) soil and seed artificially infested with the miscellaneous group of fungi; (4) soil and seed not infested artificially (control).

Each large plot was divided into 24 variety sub-plots. A sub-plot consisted of 2 rod-rows placed one foot apart. In one row a predetermined quantity of seed, depending on the variety, was sown, while 100 kernels of the same variety were sown, spaced about 2 inches apart, in the other row. The former row furnished data relative to yield, the latter data on the amount of disease.

Twenty varieties of wheat, two of oats, and two of barley were tested in each large plot of the root-rot garden in 1932 and 1933. In 1934 and 1935 twenty-four wheat varieties were tested in each plot. The varieties and selections of cereals used were secured from the Cereal Division, Dominion Rust Research Laboratory, Winnipeg, Manitoba.

Varietal-Susceptibility Trials

Field trials to determine the behaviour of several standard varieties and a large number of rust-resistant strains of wheat to root rot under artificially-induced and natural epidemics of this disease in Manitoba were begun in 1934. Similar trials were made in 1935 and 1936. The varieties and strains used were those selected by the Subcommittee on Plant

Breeding[5] for co-operative tests in Western Canada. The wheat varieties, 36 in 1934, 28 in 1935, and 22 in 1936, were tested at Winnipeg in plots artificially infested in one-half with *F. culmorum*. In addition to the Winnipeg trials, the same varieties were tested in 1934 at Brunkild in soil naturally infested with *H. sativum*. The varieties of the 1935 and 1936 experiments were tested at Winnipeg and also in fields naturally infested with *F. culmorum* at Souris and Whitewater. In 1934, 1935, and 1936, ten varieties of oats were tested at Winnipeg in plots artificially infested in one-half with *F. culmorum*.

The system of replication used in the Winnipeg experiments was 4 or 6 randomised blocks of a number of plots each, the number of plots depending on the number of varieties in the test. One-half of each plot, a variety sub-plot, was infested artificially with *F. culmorum*, while the soil of the other portion of the plot remained in the natural condition. Each sub-plot consisted of two rod-rows. The arrangement of rows was similar to that used in the root-rot garden tests, as already described. The disposition of varieties and soil treatments (artificially and naturally-infested soil) was purely at random within each block. All experiments conducted in the naturally-infested fields at Brunkild, Souris, and Whitewater, consisted of 4 or 6 randomised blocks of a large number of variety-plots each.

Details concerning the technique of infesting the soil of field plots with cereal root-rot fungi have already been described (4). Briefly stated, the method consists of applying to the soil an inoculum consisting of finely-ground oat hulls overgrown with the fungus or fungi to be introduced, and of inoculating the seed before planting by dipping it in a suspension of spores and mycelial fragments of the respective fungus, or fungi.

The strains of *F. culmorum* and *H. sativum* used for artificial infestation of the seed and of the soil were originally isolated from diseased roots of wheat plants. Previous tests (4), both in the greenhouse and in the field, had demonstrated that these fungi were definitely pathogenic to wheat. The strain of *F. culmorum* used was pathogenic also to oats.

Germination was usually complete 30 days after sowing, at which time the number of emerged plants in the spaced-seed row of each sub-plot was counted. About 10 days before full maturity, while the crop was still green, the plants in the spaced-seed row of each variety plot were lifted from the soil, examined individually, and the extent of root-rot infection on each plant recorded. In all tests herein reported a disease-rating method was used to express the extent of root-rot occurring in each variety plot. The classes and numerical ratings used to record the intensity of disease infection on individual plants of each plot, and the method of computing the disease rating, are presented in Table 1. The yield of a variety was secured by harvesting one rod row of each sub-plot and recording the weight of the threshed grain. Separate records for plant emergence,

[5] Subcommittee on Plant Breeding, Associate Committee on Field Crop Diseases (Western Section), National Research Council and Dominion Department of Agriculture, Canada.

disease rating, and yield were recorded, and the data were analyzed by the procedure described by Fisher (2) as the analysis of variance. To estimate the odds of significance, however, the F value of Snedecor (7) was used.

TABLE 1.—CLASSES, NUMERICAL RATINGS, AND DISEASE RATING USED TO RECORD THE DEGREE OF INFECTION BY *Fusarium* CULMORUM AND *Helminthosporium sativum* ON CEREAL PLANTS

Class	Degree of infection on individual plants	Numerical rating
1	No infection	0
2	Small, scattered necrotic lesions on sheath, subcrown internode, or roots	1
3	Distinct, dark lesions on basal parts, particularly on subcrown internode and roots	2
4	Large necrotic lesions on crown, subcrown internode, and roots; with loss of plant vigour	3
5	Severe rotting of basal parts; plant chlorotic, often wilted or stunted; some culms dead	4
6	Plant failed to emerge, or killed before maturity. Dead plant	5

$$\text{Disease rating} = \frac{\text{Sum of numerical ratings of individual plants} \times 100}{\text{Number of seeds sown} \times 5}.$$

The results of the various experiments are presented in the form of summary tables. These tables give the mean value of individual varieties, or the mean value of all varieties in an experiment, with an associated standard error by which differences may be compared. In this paper the difference between two quantities having the same standard error is considered significant if it is three times that standard error.

EXPERIMENTAL RESULTS

Relation of Root-Rot Infection Rating to Yield in Wheat

During the period 1931–35, special experiments were made each year to discover whether or not the amount of root-rot infection, as represented by the disease rating, was associated with yield, and to ascertain the reliability of this method of recording the intensity of root-rot infection on cereal varieties under field conditions. A short report of the earlier experiments appeared in 1934 (4). In each experiment a single standard variety of wheat was employed, and the amount of root rot in individual plots was varied by the employment of different devices to introduce pathogenic fungi into the soil. In the final analysis of the results of each experiment, disease ratings and yields of individual plots were correlated. The significance of the correlation coefficients so obtained was determined by the method described by Fisher (2).

TABLE 2.—CORRELATION SURFACE SHOWING THE RELATION BETWEEN ROOT-ROT DISEASE RATING AND YIELD IN MARQUIS WHEAT. ARTIFICIAL INFESTATION OF THE SOIL WITH *Fusarium culmorum*

Yield (bus. per acre) \ Disease Rating	50	53	56	59	62	65	68	71	73	76	79	82	85	88	91	94	97	Freq.
3																1	1	2
5																4	9	13
7																3	4	7
9		1														2	1	4
11											1					2	2	5
13								1		1		1	1				1	5
15								1				1						2
17					1		1				2	1						5
19								1			1							2
21			1			1	2				1							5
23						1	1		1			2						5
25										1								1
27	1				1				1									3
29																		0
31				1														1
Freq.	1	1	1	1	2	2	4	3	2	2	5	5	1	0	0	12	18	60

$r_{xy} = -0.8052$

$t = 10.34$ 1% point $= 2.57$

In Table 2 a correlation surface is illustrated. This shows the distribution of disease ratings and yields of 60 plots of Marquis wheat that were artificially infested with *F. culmorum* in 1933. The distribution of disease ratings and yields of 60 plots of Marquis wheat artificially infested with *H. sativum* in 1933, is illustrated in Table 3. The results of the statistical study of the data of all experiments made during the five years 1931 to 1935 are summarized in Table 4.

The results in Table 4 clearly establish the fact that root rot caused by *F. culmorum* and *H. sativum* has a very detrimental effect on the yield of wheat. Significant negative correlations were obtained in all experiments. Thus it appears that increases in the degree of root-rot infection, as expressed by the disease rating, result in decreases in yield. Considering the wide variations that occurred in replicated field plots, and the difficulties encountered in some years in producing artificially epidemics of root rot in the field, the correlations in Table 4 are very significant. From these results it was concluded that the disease rating is very closely related

TABLE 3.—CORRELATION SURFACE SHOWING THE RELATION BETWEEN ROOT-ROT DISEASE RATING AND YIELD IN MARQUIS WHEAT. ARTIFICIAL INFESTATION OF THE SOIL WITH *Helminthosporium sativum*

Yield (bus. per acre) \ Disease Rating	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	Freq.
12															1			1
13																		0
14												1		1			1	3
15									1			1			1			3
16						1			1				2					4
17						1	1			1	1	1	3	2				10
18								1		1	1	2	1	1				7
19						1					2			1				4
20								1	1			1	1					4
21							1	1	2	1	1		1	1				8
22										2	1	2	1					6
23						1												1
24																		0
25			1	1														2
26						1	1	1										3
27					1			1										2
28	1							1										2
Freq.	1	0	1	1	1	5	3	6	5	5	6	8	9	6	2	0	1	60

$r_{xy} = -0.6223$

$t = 6.05$ 1% point $= 2.57$

TABLE 4.—CORRELATION BETWEEN THE DEGREE OF ROOT-ROT INFECTION, AS EXPRESSED BY THE DISEASE-RATING METHOD, AND YIELD IN WHEAT

Year	Variety	Tested against	Correlation coefficient	t*
1931	Mindum	*F. culmorum* and *H. sativum*	−0.52	4.47
1931	Marquis	*F. culmorum* and *H. sativum*	−0.32	2.48
1932	Mindum	*F. culmorum* and *H. sativum*	−0.63	5.93
1932	Marquis	*H. culmorum* and *H. sativum*	−0.69	6.22
1933	Marquis	*F. culmorum*	−0.80	10.34
1933	Marquis	*H. sativum*	−0.62	6.05
1934	Pentad × Marquis	*F. culmorum*	−0.55	4.96
1935	Pentad × Marquis	*F. culmorum*	−0.37	3.07

*5% point = 1.95. 1% point = 2.57.

to yield, and constitutes an accurate measure of the amount of root rot in wheat. The disease rating was therefore considered sufficiently reliable to be employed in estimating the field reactions of varieties and selections of cereals to root rot caused by *F. culmorum* and *H. sativum*.

Infection in Field Plots

The preliminary experiments of 1930 and 1931 demonstrated that naturally-infested soil would be most suitable to determine the relative susceptibility of cereal varieties to root-rot caused by *F. culmorum* and *H. sativum*. As it was found difficult to secure each year suitable naturally-infested fields for experimental purposes, it was necessary, in order to make satisfactory annual root-rot tests, to develop an efficient and a practical technique for inducing positive attacks with *F. culmorum* and *H. sativum* in field plots. The results of experiments in which positive attacks with *F. culmorum* have been artificially induced in plots of wheat have appeared in an earlier paper (4). The results obtained in the present root-rot garden tests and varietal trials are summarized here. Earlier in this paper, reference was made to treatment of the soil.

Root-Rot Garden Tests

A complete analysis of variance for plant emergence, disease rating, and yield was made for the root-rot garden tests of 1932, 1933, 1934, and 1935. The analyses in Tables 5 and 6 establish significant differences, both with respect to number of plants emerged and disease rating, between the 4 soil treatments used in the root-rot garden. In every case the *F* values for soil treatments are much greater than the 1% probability values. An examination of the yield data (Table 7) shows that significant differences in yield for soil treatments were not obtained in 1932 and 1933. In 1934 and 1935, however, these yield differences were highly significant. A summary of the mean results of all wheat varieties tested annually in the root-rot garden during the 4 years 1932–35, with the standard errors associated with them, showing the effect of artificial infestation of field plots on plant emergence, disease rating, and yield, are given in Table 8.

The results in Table 8 show that even though inoculum of a root-rotting fungus was not added to the seed or to the soil (control), a considerable amount of infection occurred on the roots and basal parts of wheat plants. In each year of the test the number of plants that emerged in the 100-seed rows of the natural-soil plots in the root-rot garden was quite low, and the degree of root-rot infection in these plots was relatively severe. Thus it would appear that fungi pathogenic to the roots and basal parts of wheat plants naturally inhabit the soil and cause considerable injury to wheat crops. However, as Table 8 shows, plant emergence was markedly reduced and the amount of root-rot considerably increased by infesting the soil artificially with *F. culmorum*, or with the miscellaneous group of fungi (*F. culmorum*, *H. sativum*, *Fusarium* spp., and others).

In 1932 and 1933 the yield of wheat was not influenced by the introduction of pathogenic fungi into the soil, but, in 1934 and 1935, significant differences in yield between the control plots and those artificially infested with *F. culmorum* or with the miscellaneous group of fungi were obtained.

TABLE 5.—ANALYSES OF VARIANCE FOR PERCENTAGE PLANT EMERGENCE IN WHEAT VARIETIES. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1932	Controlled error	6	7,453.1	1,242.2		
	Soil treatments	3	17,753.9	5,917.9	15.11	6.55
	Error (a)	10	3,914.4	391.4		
	Total	19	29,121.4			
	Varieties	19	26,757.5	1,408.3	23.17	1.85
	Varieties × soil treatments	57	7,393.9	129.7	2.13	1.14
	Error (b)	304	18,476.4	60.7		
	Total	380	52,627.8			
1933	Controlled error	8	2,733.2	341.6		
	Soil treatments	3	70,321.1	23,440.4	124.9	5.95
	Error (a)	12	2.250.6	187.5		
	Total	23	75,304.9			
	Varieties	19	29,385.3	1,546.6	26.98	1.84
	Varieties × soil treatments	57	8,373.2	146.9	2.56	1.11
	Error (b)	380	21,783.5	57.3		
	Total	456	59,542.0			
1934	Controlled error	8	30,348.3	3,793.5		
	Soil treatments	3	82,619.1	27,539.7	53.51	5.95
	Error (a)	12	6,175.0	514.6		
	Total	23	119,142.4			
	Varieties	23	14,856.4	645.9	8.22	1.83
	Varieties × soil treatments	69	5,261 4	76.2	—	1.08
	Error (b)	460	36,142.2	78.6		
	Total	552	56,260.0			
1935	Controlled error	8	10,030 8	1,253.8		
	Soil treatments	3	118,764.7	39,588.2	61.49	5.95
	Error (a)	12	7,725.1	643.8		
	Total	23	136,520.6			
	Varieties	23	8,928 6	388.2	6.47	1.83
	Varieties × soil treatments	69	12,518.9	181.4	3.02	1.08
	Error (b)	460	27,587.2	59.9		
	Total	552	49,034.7			

In all years, plots infested with *H. sativum* yielded slightly less than did the natural-soil controls, but the difference observed each year was not significant statistically. In 1934 the average yield of 24 wheat varieties was decreased 6.5 bushels per acre by artificial infestation of the soil with *F. culmorum*.

An examination of the analyses of variance for yield (Table 7), and to some extent for plant emergence (Table 5), and of the summarized

TABLE 6.—ANALYSES OF VARIANCE FOR ROOT-ROT DISEASE RATING IN WHEAT VARIETIES. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1932	Controlled error	6	5,200.4	866.7		
	Soil treatments	3	7,489.6	2,496.5	11.49	6.55
	Error (a)	10	2,173.8	217.3		
	Total	19	14,863.8			
	Varieties	19	10,156.6	534.5	16.91	1.85
	Varieties × soil treatments	57	3,317.8	58.2	1.84	1.14
	Error (b)	304	9,615.8	31.6		
	Total	380	23,090.2			
1933	Controlled error	8	2,277.0	284.6		
	Soil treatments	3	31,068.8	10,356.2	150.96	5.95
	Error (a)	12	823.9	68.6		
	Total	23	34,169.7			
	Varieties	19	10,628.6	559.4	17.59	1.84
	Varieties × soil treatments	57	3,092.2	54.2	1.70	1.11
	Error (b)	380	12,105.7	31.8		
	Total	456	25,826.5			
1934	Controlled error	8	13,924.9	1,740.6		
	Soil treatments	3	32,013.9	10,671.3	33.13	5.95
	Error (a)	12	3,864.8	322.1		
	Total	23	49,803.6			
	Varieties	23	5,446.3	236.8	7.76	1.83
	Varieties × soil treatments	69	2,521.2	36.5	1.19	1.08
	Error (b)	460	14,018.6	30.5		
	Total	552	21,986.1			
1935	Controlled error	8	5,924.2	740.5		
	Soil treatments	3	47,644.0	15,881.3	137.62	5.95
	Error (a)	12	1,384.9	115.4		
	Total	23	54,953.1			
	Varieties	23	4,416.6	192.0	6.50	1.83
	Varieties × soil treatments	69	4,430.8	64.2	2.17	1.08
	Error (b)	460	13,588.7	29.5		
	Total	552	22,436.1			

results in Table 8, indicates that there was a progressive annual increase from 1932 to 1935 in the amount of root-rot occurring in plots infested artificially with *F. culmorum*. A similar increase occurred in plots infested artificially with the mixed group of fungi. Unfortunately, the root-rot garden tests were not designed to determine the pathogenic effect on wheat of individual organisms of this mixed group of fungi. Thus, no evidence was produced from the tests to show that any fungus of the mixed group, other than *F. culmorum*, was responsible for the progressive annual increase

TABLE 7. ANALYSES OF VARIANCE FOR YIELD IN WHEAT VARIETIES. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1932	Controlled error	6	3,841.7	640.3		
	Soil treatments	3	306.8	102.3	0.92	6.55
	Error (a)	10	1,116.8	111.7		
	Total	19	5,265.5			
	Varieties	19	9,711.8	511.1	15.25	1.85
	Varieties × soil treatments	57	1,996.5	35.0	1.04	1.14
	Error (b)	304	10,186.6	33.5		
	Total	380	21,894.9			
1933	Controlled error	8	682.4	85.3		
	Soil treatments	3	1,511.7	503.9	3.83	5.95
	Error (a)	12	1,576.1	131.3		
	Total	23	3,770.2			
	Varieties	19	6,482.4	341.2	28.67	1.84
	Varieties × soil treatments	57	2,024.4	35.5	2.98	1.11
	Error (b)	380	4,521.9	11.9		
	Total	456	13,028.7			
1934	Controlled error	8	5,167.1	645.9		
	Soil treatments	3	8,130.9	2,710.3	9.55	5.95
	Error (a)	12	3,403.7	283.6		
	Total	23	16,701.7			
	Varieties	23	19,013.1	826.6	12.97	1.83
	Varieties × soil treatments	69	2,084.4	30.2	0.47	1.08
	Error (b)	460	29,337.6	63.7		
	Total	552	50,435.1			
1935	Controlled error	8	691.9	86.5		
	Soil treatments	3	1,941.3	647.1	32.51	5.95
	Error (a)	12	239.3	19.9		
	Total	23	2,872.5			
	Varieties	23	29,369.4	1,276.9	77.85	1.83
	Varieties × soil treatments	69	2,198.8	31.8	1.93	1.08
	Error (b)	460	7,550.2	16.4		
	Total	552	39,118.4			

in the amount of root rot observed in plots infested annually with this group of fungi during the four years 1932–35.

Varietal-Susceptibility Trials

Further information concerning the effectiveness of the methods used to produce positive root-rot attacks on wheat with *F. culmorum* was provided by the results of the varietal tests made at Winnipeg in 1934, 1935, and 1936. In these tests one-half of each variety plot was artificially infested with

TABLE 8.—EFFECT OF ARTIFICIAL INFESTATION OF THE SOIL WITH *Fusarium culmorum*, WITH *Helminthosporium sativum*, AND WITH A MISCELLANEOUS GROUP OF ROOT-ROTTING FUNGI ON PLANT EMERGENCE, INCIDENCE OF DISEASE, AND YIELD OF WHEAT. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Soil infested with	1932	1933	1934	1935
	Percentage of plants emerged*			
Fusarium culmorum	40	32	27	32
Miscellaneous fungi	44	32	25	32
Helminthosporium sativum	52	55	48	61
Control (ordinary soil)	57	57	51	61
Standard error	±1.98	±1.25	±1.89	±2.11
	Disease rating*			
Fusarium culmorum	73.1	81.0	76.4	80.8
Miscellaneous fungi	70.3	80 7	73.7	82.0
Helminthosporium sativum	65.0	65.8	61.7	63.5
Control (ordinary soil)	62.2	63.9	59.1	63.0
Standard error	±1.47	±0.76	±1.49	±0.89
	Yield (bus. per acre)*			
Fusarium culmorum	31.0	15.3	25.9	12.3
Miscellaneous fungi	32.5	16.1	23.4	11.9
Helminthosporium sativum	31.3	18.7	31.4	15.4
Control (ordinary soil)	33.1	19.6	32 4	16.1
Standard error	Insign.	Insign.	±1.40	±0.37

* Each value represents the mean of 20 varieties (120 plots) in 1932 and 1933, and 24 varieties (144 plots) in 1934 and 1935.

F. culmorum, as already described under experimental methods. An analysis of the separate data of each test was made. For the sake of brevity, however, all the analyses are not reproduced. Those given in Table 9 are only the analyses for disease rating and for the different years. The mean results of these varietal tests, showing the effect of artificial infestation of the soil with *F. culmorum* on the number of plants emerged, degree of root-rot infection, and yield, are summarized in Table 10.

An examination of Table 9 shows that significant differences in disease rating for soil treatments (artificially and naturally-infested soil) were obtained in 1934, 1935, and 1936. In every instance the variance for soil treatments was much greater than the variance for error, the *F* value being very much larger than the 1% probability value. Separate analyses of the plant emergence and yield data of these experiments similarly established wide and significant differences between artificially-infested plots and natural-soil controls.

The results in Tables 8 and 10 show that positive attacks of root-rot were induced each year by inoculating the seed and infesting the soil with *F. culmorum*. Statistically, the effectiveness of this method of inducing positive attacks of common root-rot in field plots was established with a

TABLE 9.—ANALYSES OF VARIANCE FOR ROOT-ROT DISEASE RATING IN WHEAT. VARIETAL TESTS, WINNIPEG, 1934–36

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1934	Controlled error	7	4,133.3	590.4		
	Varieties	35	4,163.5	118.9	1.86	1.39
	Error (a)	101	6,447.9	63.8		
	Total	143	14,744.7			
	Soil treatments	1	15,558.4	15,558.4	270.11	6.90
	Varieties × treatments	35	1,044.9	29.8		
	Error (b)	108	6,223.2	57.6		
	Total	144	22,826.5			
1935	Controlled error	7	91.8	13.1		
	Varieties	27	9,892.4	366.3	51.24	1.47
	Error (a)	77	550.7	7.1		
	Total	111	10,534.9			
	Soil treatments	1	4,576.5	4,576.5	829.09	6.96
	Varieties × treatments	27	1,669.4	61.8	11.20	1.47
	Error (b)	84	464.1	5.5		
	Total	112	6,710 0			
1936	Controlled error	3	598.5	199.5		
	Varieties	21	3,853.7	183.5	10.08	2.12
	Error (a)	63	1,150.5	18.2		
	Total	87	5,602.7			
	Soil treatments	1	371.4	371.4	35.03	7.01
	Varieties × treatments	21	636.9	30.3	2.85	2.07
	Error (b)	66	706.0	10.6		
	Total	88	1,714.3			

high degree of probability. The results of the root-rot garden tests (Table 8), and of the Winnipeg varietal tests (Table 10), show that root-rot caused by *F. culmorum* has a very detrimental effect on the yield of wheat. As in previous studies (4), the results with *H. sativum* were not satisfactory. Contrary to the results obtained by Sallans (6) in Saskatchewan, all methods used in the present investigation failed to give a satisfactory epidemic of *Helminthosporium* root rot in field plots of wheat. Further experiments to determine the cause of these failures in Manitoba with *H. sativum* are required.

The mean squares for disease rating obtained for the interaction of soil treatments and varieties in the root-rot garden tests (Table 6), and in the variety tests (Table 9), indicate, in general, that wheat varieties behave differently under various conditions of soil treatment. The nature of the conditions that bring about this differential effect of soil treatment on wheat varieties is not at present clear.

TABLE 10.—EFFECT OF ARTIFICIAL INFESTATION OF THE SOIL WITH *F. culmorum* ON PLANT EMERGENCE, INCIDENCE OF DISEASE, AND YIELD OF WHEAT. VARIETAL TESTS, WINNIPEG, 1934–36

Soil treatment	1934	1935	1936
	Percentage of plants emerged*		
Artificially infested with *F. culmorum*	32.7	32.3	51.9
Control (natural soil)	54.0	69.4	66.5
Decrease due to *F. culmorum*	21.3	37.1	14.6
Standard error	±0.94	±0.69	±0.94
	Disease rating*		
Artificially infested with *F. culmorum*	69.9	82.7	68.2
Control (natural soil)	55.2	62.0	57.7
Increase due to *F. culmorum*	14.7	20.7	10.5
Standard error	±0.63	±0.51	±0.77
	Yield (bus. per acre)*		
Artificially infested with *F. culmorum*	21.9	7.1	18.5
Control (natural soil)	34.3	16.2	21.4
Decrease due to *F. culmorum*	12.4	9.1	2.9
Standard error	±0.49	±0.22	±0.35

* Each value represents the general mean of 36 varieties (144 plots) in 1934, 28 varieties (112 plots) in 1935, and 22 varieties (132 plots) in 1936.

Behaviour of Wheat Varieties

Varietal Susceptibility

During the four years 1932–35, the susceptibility of a large number of varieties and strains of wheat to various root-rotting fungi were compared in the root-rot garden plots at Winnipeg. In 1934, 1935, and 1936, tests were also made at several stations in Manitoba to determine the behaviour of several standard varieties and a large number of rust-resistant strains of wheat to root-rot under natural field conditions. The results of these varietal trials are given in Tables 11 and 12, and in Figure 1.

To economize space, tables showing the results obtained in the root-rot garden in 1935 and 1936 are not reproduced; those of 1933 and 1934 are presented in Tables 11 and 12. The varieties are arranged in order of resistance to *F. culmorum*, and numbers are assigned to them to indicate their relative resistance to the other fungi.

From Tables 11 and 12 it is evident that, in 1933 and 1934, all of the wheat varieties were quite susceptible to the fungi against which they were tested. There were, however, significant variations in the susceptibility of the varieties to these fungi. The results of the root-rot garden tests of 1935 and 1936 were essentially similar to those of 1933 and 1934.

TABLE 11.—REACTION OF STANDARD VARIETIES AND NEW RUST-RESISTANT STRAINS OF WHEAT TO SOME COMMON ROOT-ROTTING FUNGI IN 1933

Variety	Station No.	Soil infested with:							
		Fusarium culmorum		Miscellaneous fungi		*Helminthosporium sativum*		Control (natural soil)	
		D.R.[1]	Arr.[2]	D.R.	Arr.	D.R.	Arr.	D.R.	Arr.
Mindum × Pentad	533	71.6	1	69.9	2	59.5	1	60.6	5
Pentad × Marquis	1005	72.5	2	76.9	7	61.6	4	62.9	9
Double Cross	1246	73.7	3	74.6	3	63.5	8	58.3	3
H-44-24 × Reward	975	75.1	4	75.5	4	59.8	2	60.2	4
Ceres	127	76.6	5	76.5	6	67.2	11	65.6	14
Marquis	84	76.8	6	76.3	2	60.8	4	57.5	1
H-44-24 × Marquis	711	77.3	7	80.3	12	61.7	6	58.1	2
Pentad × Marquis	729	77.6	8	77.7	6	60.2	3	61.1	6
Mindum × Pentad	527	77.8	9	79.8	10	68.0	14	68.3	18
Mindum × Pentad	534	78.1	10	75.9	5	65.1	10	67.1	17
Pentad	203	78.8	11	79.3	9	64.1	9	65.9	15
Pentad × Marquis	1000	81.1	12	80.0	11	67.4	13	65.2	12
Hope × Reward	C.26.47	82.2	13	83.6	14	68.7	16	62.0	7
H-44-24 × Marquis	712	82 7	14	81.6	13	62.8	7	62.3	8
Reward	79	84.9	15	86.2	16	74.6	20	65.2	11
Pentad × Marquis	986	88.8	16	84 8	15	68.4	15	63.9	10
Mindum	568	89.6	17	87.8	17	70.8	17	65.5	13
H-44-24 × Reward	978	90.7	18	87.8	18	67.3	12	66.2	17
Reliance × Reward	1110	91.0	19	89.2	19	73.9	19	69.8	19
Pentad × Marquis	12.10.3	94.2	20	94.3	20	70.8	18	72.6	20
Standard error		±2.30		±2.30		±2.30		±2.30	

[1] D.R. = Disease rating. Each value is the mean infection rating of six plots.
[2] Arr. = Arrangement of varieties in order of resistance.

During the course of these tests, wheat varieties most resistant to *F. culmorum* were equally resistant to *H. sativum* and to the miscellaneous group of fungi, while varieties susceptible to *F. culmorum* were fairly consistently susceptible to the other root-rot fungi. In other words, there was a very significant correlation between the reactions of the wheat varieties to fungi most commonly associated with common root rot in Manitoba.

In 1934, eighteen varieties were tested against *F. culmorum* and *H. sativum* in artificially-infested plots at Winnipeg and in naturally-infested grain fields at Winnipeg and Brunkild, Manitoba. The results of these tests are given in Table 13, and provide further evidence that in any given season wheat varieties are quite stable in their reaction to *F. culmorum* and *H. sativum*, the two most common root-rotting fungi of wheat in the Prairie Provinces.

The relative susceptibility of several standard varieties and a large number of rust-resistant selections of wheat to root rot when tested in naturally and artificially-infested fields in Manitoba in 1934, 1935, and 1936 is shown in Figure 1. An examination of Figure 1 shows that, in 1934, the 5 varieties most resistant to *F. culmorum* at Winnipeg (Winnipeg A) were 3rd, 2nd, 1st, 5th and 6th in order of resistance when tested at Brunkild in field plots naturally infested with *H. sativum*. The same varieties were 9th, 1st, 7th, 6th and 8th, respectively, when grown in naturally-infested soil at Winnipeg (Winnipeg B). The behaviour of the

TABLE 12.—REACTION OF STANDARD VARIETIES AND NEW RUST-RESISTANT STRAINS OF WHEAT TO SOME COMMON ROOT-ROTTING FUNGI IN 1934

Variety	Station No.	Soil infested with:							
		Fusarium culmorum		Miscellaneous fungi		*Helmintho-sporium sativum*		Control (natural soil)	
		D.R.*	Arr.†	D.R.	Arr.	D.R.	Arr.	D.R.	Arr.
Ceres	127	64.9	1	66.7	1	50.0	1	53.3	2
Pentad × Marquis	986	67.9	2	73.8	2	59.2	6	53.9	3
Hope × Reward	C.26.59	69.1	3	76.4	13	56.4	2	56.0	5
Reliance × Hope	1110	69.3	4	75.2	7	57.0	4	49.5	1
Pentad	203	69.8	5	76.0	10	63.5	15	57.1	7
Hope × Reward	C.26.47	69.9	6	80.1	22	64.3	19	58.3	11
Thatcher	2303	72.1	7	74.6	3	57.5	5	62.9	19
Marquis	84	72.6	8	74.6	4	60 2	7	58.8	14
Pentad × Marquis	729	72.9	9	77.1	17	61.7	10	56.6	6
Reward	79	73.0	10	75.2	8	56.7	3	58.7	12
Double Cross × Ceres	625	73.0	11	74.8	5	61.6	9	58.2	10
H-44-24 × Marquis	702	73.4	12	78 6	19	63.9	18	57.1	8
H-44-24 × Reward	967	74.3	13	76 0	11	63 7	17	58.9	15
H-44-24 × Marquis	590	74 5	14	74.9	6	67.3	23	59 6	16
Pentad × Marquis	1005	75.8	15	76 7	15	63.0	14	64.5	22
H-44-24 × Reward	978	75.9	16	79.4	20	65.5	22	57.2	9
H-44-24 × Marquis	712	76 2	17	79.7	21	64.3	20	60.2	17
Hope × Reward	C.26.123	76 6	18	75.6	9	62.9	13	54 9	4
Hope × Reward	1134	76.6	19	76.1	12	60.9	8	58 7	13
H-44-24 × Marquis	711	76 7	20	77.0	16	64.9	21	61.5	18
Pentad × Marquis	12.10.3	77.0	21	80.2	23	62.1	12	63 2	20
H-44-24 × Reward	975	77.6	22	76.5	14	61.8	11	64.7	23
H-44-24 × Reward	716	77.6	23	80.5	24	67.6	24	65.0	24
Mindum	568	80 1	24	77.3	18	63.5	16	64.1	21
Standard error		±2.25		±2.25		±2.25		±2.25	

* D.R. = Disease rating. Each value represents the mean infection rating of six plots.
† Arr. = Arrangement of varieties in order of resistance.

28 wheat varieties was quite consistent when tested at 3 different stations in 1935, that is, the group of varieties with most resistance at one station was composed of the varieties showing the most resistance at the other stations, and varieties most susceptible at one station were most susceptible at the other stations. Results essentially similar to those of 1934 and 1935 were obtained in 1936.

In general, the results show that each year during the course of the investigation some of the standard varieties and new rust-resistant selections of wheat were fairly consistently resistant to *Fusarium-Helminthosporium* root rot, while other varieties and selections were consistently susceptible. Wheat varieties resistant when *F. culmorum* was the predominating pathogenic fungus in the soil were most resistant when *H. sativum* was the most common root-rotting fungus present, while susceptibility to one of these organisms was significantly associated with susceptibility to the other.

From Figure 1 it is evident that wheat varieties vary considerably in their susceptibility to *Fusarium-Helminthosporium* root rot. In 1935, for example, the disease-infection rating of individual varieties in the Winnipeg test varied from 69 to 96. Statistically significant variations in the sus-

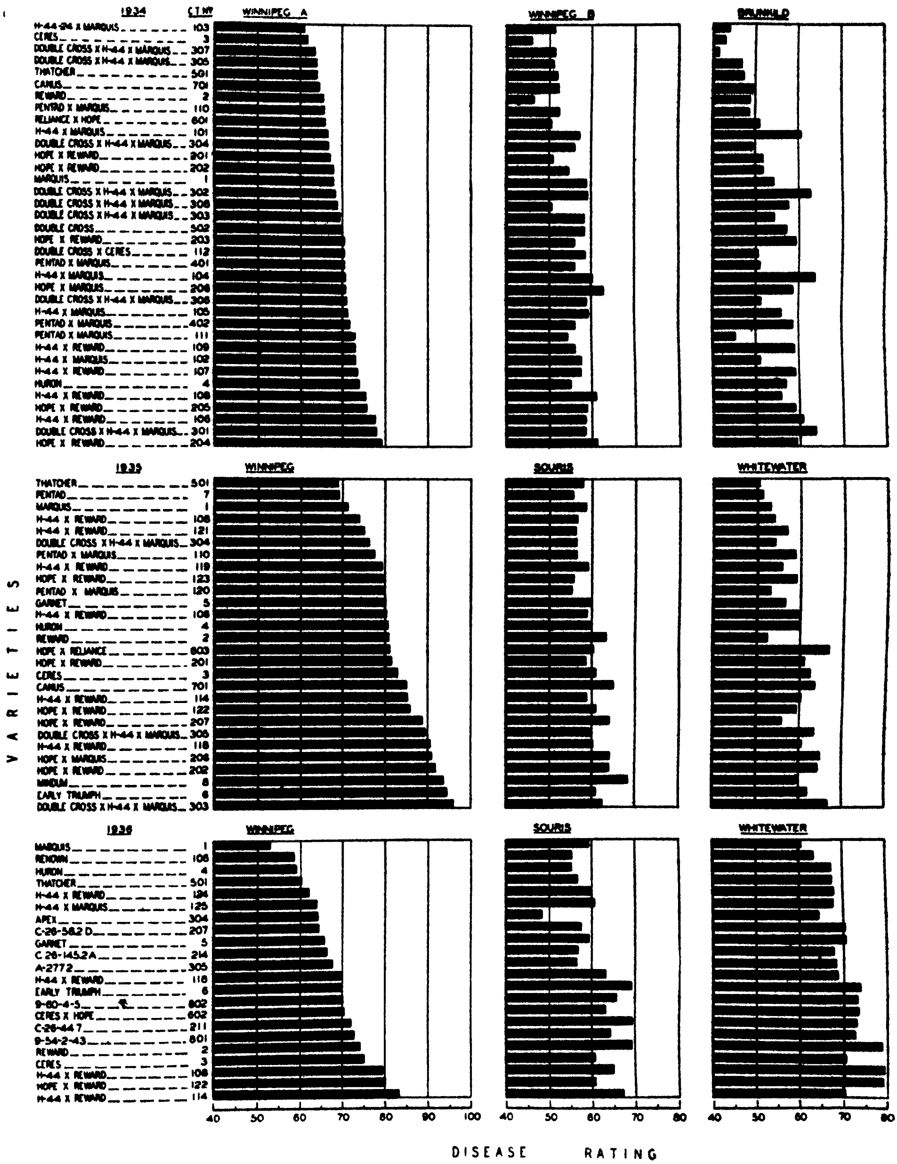

FIGURE 1. Reaction of varieties and rust-resistant selections of wheat to root rot caused by *Fusarium culmorum* and *Helminthosporium sativum*. Results of field tests made in Manitoba in 1934, 1935, and 1936. The Winnipeg tests,—*Winnipeg A* and *Winnipeg*—were made in soil infested artificially with *F. culmorum*. In *Winnipeg B* test of 1934 the soil was infested naturally with *F. culmorum* and other fungi. The Brunkild field was naturally infested with *H. sativum*. Tests at Souris and Whitewater were made in soil naturally infested with *F. culmorum* and other fungi.

ceptibility of wheat varieties to root rot were observed in all tests made during the 3-year period 1934–36.

The results of observations and experiments over a period of years have indicated that environmental factors, age of the plant, as well

TABLE 13.—REACTION OF WHEAT VARIETIES TO ROOT ROT CAUSED BY *Fusarium culmorum* AND *Helminthosporium sativum* UNDER NATURAL AND ARTIFICIAL ATTACKS OF THESE FUNGI IN MANITOBA IN 1934

Variety	Station No.	Disease rating*							
		Kind of soil infestation							
		Fusarium culmorum				*Helminthosporium sativum*			
		Artificial	Natural	Mean	Arr.†	Artificial	Natural	Mean	Arr.†
Ceres	127	64.9	53.3	59.1	1	50.0	43.0	46.5	1
Reliance × Hope	1110	69.3	49.5	59.4	2	56.9	51.0	53.9	4
Pentad × Marquis	729	62.9	56.6	59.8	3	61.7	58.4	60.0	13
Pentad × Marquis	986	67.9	53.9	60.9	4	59.2	45.5	52 3	3
Hope × Reward	C.26.59	69.1	56.0	62.5	5	56.4	51.9	54.1	5
Hope × Reward	C.26.47	69.9	58.3	64.1	6	64.3	58.7	61.5	15
H-44-24 × Marquis	702	73.4	57.1	65.2	7	63.9	51.2	57.5	12
Double Cross × Ceres	625	73.0	58.3	65.6	8	61.6	50.6	56.1	7
Marquis	84	72.6	58.8	65.7	9	60.1	54 8	57 4	10
Reward	79	73.0	58.7	65.8	10	56.7	51.9	54.3	6
H-44-24 × Reward	978	75.9	57.2	66.5	11	65.5	58.7	62.1	16
Thatcher	2303	72.1	62.9	67.5	12	57.5	46.6	52.0	2
Hope × Reward	1134	76.6	58.7	67.6	13	62.9	52.0	57.4	11
H-44-24 × Marquis	712	76.2	60.2	68.2	14	64.3	56.0	60.1	14
H-44-24 × Marquis	711	76.7	61.5	69.1	15	64.9	63.8	64.3	17
Pentad × Marquis	12.10.3	77.0	63.2	70.1	16	62.1	50.9	56 5	8
H-44-24 × Reward	975	77.6	65.7	71.6	17	61.8	52.5	57.1	9
H-44-24 × Reward	716	78.6	69.0	73.8	18	68.6	60.3	64 4	18
Standard error		±2.25	±2.25	±1.59		±2.25	±3 50	±2.46	

* Each value represents the mean infection rating of six plots.
† Arr. = Arrangement of varieties in order of resistance.

as varietal difference, play a very important part in determining the occurrence and severity of root-rot attacks on wheat. Furthermore, it is recognized that, owing to the interaction of these and other factors, considerable variation in the severity of root-rot infection on individual varieties occurs from season to season. It is well, therefore, in determining the susceptibility of a variety to root rot, to consider the behaviour of the variety over a series of years.

From this point of view it is interesting to compare the susceptibility to root rot of three new rust-resistant varieties of wheat, Thatcher, Apex, and Renown, with that of three standard and commonly-grown varieties, Marquis, Reward, and Garnet. The results of tests made with these varieties during the 3-year period 1934–36 are summarized in Table 14.

It is evident from Table 14 that, in the process of breeding and selecting varieties resistant to rust, some progress has been made in securing strains of wheat resistant to root rot. This result might be expected, for, in the process of breeding for rust-resistance, only wheat strains of high yielding ability and of good grain quality were finally selected and increased for commercial distribution. The results in Table 14 show that Apex and Thatcher were, during the three years 1934–36, slightly more resistant to root rot than were the standard varieties Marquis, Reward and Garnet.

TABLE 14.—SUSCEPTIBILITY OF SOME STANDARD AND RUST-RESISTANT VARIETIES OF SPRING WHEAT TO *Fusarium-Helminthosporium* ROOT ROT, 1934–36

Variety	Disease rating*						
	Root-rot garden studies†		Varietal tests‡			Mean of tests 1934–36	General mean
	1934	1935	1934	1935	1936		
Marquis	66.6	71.6	60.5	61.2	59.7	63.9	
Reward	65.9	71.7	53.6	61.8	73.3	65.3	66.9
Garnet	—	72.8	—	68.3	73.5	71.5	
Apex	—	69.1	57.6	62.0	57.1	61.4	
Thatcher	66.8	66.8	54.3	58.5	63.7	62.0	62.7
Renown	72 2	65.6	66.4	63.2	56.6	64.8	

* Disease rating computed on basis of number of seeds sown; highest numerical rating for non-emergence.
† Each value represents the mean of four tests (24 plots).
‡ Co-operative tests of new wheat varieties conducted by the Sub-committee on Plant Breeding, Associate Committee on Field Crop Diseases (Western Section), National Research Council and Dominion Department of Agriculture, Ottawa. Each value represents the mean of replicated tests at three stations in 1934, and at four stations in 1935 and 1936.

On the other hand, Renown was considerably more resistant than Garnet, but it did not differ significantly from Marquis and Reward in its reaction to root rot.

Germination and Plant Emergence.

The germination capacity, or rather the ability of the grain to produce young plants, has been generally considered an important index of the resistance of wheat varieties to common root rot, particularly the seedling-blight phase of this disease. In the variety tests made in Manitoba in 1934, 1935, and 1936, the number of plants that emerged in the 100-seed rows of each variety plot was counted about 4 weeks after planting. The results of counts made in various artificially and naturally-infested soils are summarised in Table 15.

The results in Table 15 show that there is a significant variation in the ability of wheat varieties to germinate and produce young plants. The average results with 36 varieties in 1934 (1,200 seeds of each) show that the range in plant emergence of individual varieties was from 36 to 64%. In 1935 the range in plant emergence of 28 varieties (1,200 seeds of each) was from 53 to 74%. The varietal range in percentage of plants emerged, based on the average count of four tests in 1936 with 22 varieties (2,000 seeds of each), was from 42 to 67, or a difference of 25%. The ability of the seed of some wheat varieties, especially the new rust-resistant varieties Apex and Thatcher, to germinate and produce young plants was uniformly high in all years and in all tests, while the seed of some of the varieties gave consistently low figures for the number of emerged plants.

The results of the Winnipeg tests on artificially and naturally-infested soil show that, during the three years 1934–36, artificial infestation of the seed and of the soil with *F. culmorum* markedly reduced plant emergence. In 1935, the average difference in number of plants emerged of 28 varieties between artificially and naturally-infested plots was 37.1%.

From Table 15 it is evident that, under Manitoba conditions, wheat varieties vary considerably in their ability to germinate and produce young plants. In the case of several of the varieties tested, the percentage of plant emergence was very low. This suggests that, in any wheat improvement programme, the problem of breeding to increase the ability of

TABLE 15.—THE ABILITY OF WHEAT VARIETIES TO GERMINATE AND PRODUCE YOUNG PLANTS IN FIELD PLOTS NATURALLY AND ARTIFICIALLY INFESTED WITH *Fusarium culmorum*. SUMMARY OF RESULTS IN 1934, 1935, AND 1936

Year	Station	Number of varieties*	Kind of soil infestation	Percentage of plants emerged (after 35 days)†	
				Range within varieties	Average of all varieties
1934	Winnipeg	36	Artificial	17–46	32 7
	Winnipeg	36	Natural	21–69	54 1
	Brunkild	36	Natural‡	44–77	59 4
	Mean of 3 tests			36–64	48 7
1935	Winnipeg	28	Artificial	9–54	32 4
	Winnipeg	28	Natural	58–82	69 5
	Souris	28	Natural	82–95	89 8
	Whitewater	28	Natural	26–75	63 5
	Mean of 4 tests			53–74	63 8
1936	Winnipeg	22	Artificial	32–74	52 0
	Winnipeg	22	Natural	44–79	66 5
	Souris	22	Natural	41–80	62 1
	Whitewater	22	Natural	36–58	47 0
	Mean of 4 tests			42–67	56 9

* Standard varieties and new rust-resistant strains of wheat selected by the Subcommittee on Plant Breeding, Associate Committee on Field Crop Diseases

† Results based on the mean of four plots (400 seeds) of each variety, except in tests at Souris and Whitewater in 1936 when the results represent the mean of six plots (600 seeds) of each variety

‡ Varieties grown at Brunkild in soil naturally infested with *Helminthosporium sativum*

the grain to produce strong young plants, is one deserving particular attention. Further studies to determine the effect of this character on the resistance of cereal varieties to common root rot are required. The importance of breeding spring wheats to raise the germinability of the grain has been recently emphasized by Navolotskiĭ and Navoltskaja (5).

Behaviour of Oat Varieties

Tests to determine the relative susceptibility of oat varieties to root rot caused by *Fusarium culmorum* were begun at Winnipeg in 1934. In that year 10 varieties, including new rust-resistant strains and standard varieties, were grown in plots artificially infested in one-half with *F. culmorum*. This test was repeated in 1935 and 1936. The technique of soil infestation, the arrangement of plots, and the methods of recording and analysing experimental data employed in the oat tests were similar to those used in the Winnipeg root-rot tests with wheat, and have already been

described. All varieties and strains used were secured from the Cereal Division, Dominion Rust Research Laboratory, Winnipeg, Man. Separate data of each test were subjected to statistical treatment. Table 16 gives the complete analyses of variance for plant emergence and disease rating of these experiments.

TABLE 16.—ANALYSES OF VARIANCE FOR PERCENTAGE OF PLANTS EMERGED AND DISEASE RATING IN OATS. VARIETAL TESTS, WINNIPEG, 1934–36

Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
	Percentage of plants emerged				
Replicates	11	5,717.73	519.79		
Years	2	2,679 69	1,339.84	18.76	4.82
Varieties	9	4,210.32	467.81	6.55	2.69
Varieties × years	18	6,377.66	354.31	4.96	2.37
Error (a)	99	7,069 67	71.41		
Total	139	26,055.07			
Treatments (soil)	1	35,100.80	35,100.80	567 79	6 84
Treatments × varieties	9	3,284.52	364 94	5.90	2 66
Treatments × years	2	8,391.02	4,195.51	57.86	4.78
Treatments × varieties × years	18	2,640.91	146.71	2.37	2.33
Error (b)	110	6,800 25	61.82		
Total	140	56,217.50			
	Disease rating				
Replicates	11	2,960.48	269.13		
Years	2	62,102.80	31,051.40	533.52	4.82
Varieties	9	2,524.36	280.48	4.82	2.69
Varieties × years	18	3,675.94	204.22	3.50	2.37
Error (a)	99	5,761.31	58.20		
Total	139	77,024.89			
Treatments (soil)	1	20,960.68	20,960.68	610.92	6 84
Treatments × varieties	9	1,818.92	202.10	5.89	2.66
Treatments × years	2	7,409 13	3,704.56	107.97	4.78
Treatments × varieties × years	18	1,444.40	80.24	2.33	2.33
Error (b)	110	3,774.45	34.31		
Total	140	35,407.58			

The analyses in Table 16 establish significant differences, both with respect to plant emergence and disease rating, between artificially and naturally-infested soil. In both cases the variance for soil treatments is much greater than the error variance. Thus the results indicate that a high degree of significance can be attached to the method of inducing positive root-rot attacks on oats by adding inoculum of *F. culmorum* to the seed and soil. The mean varietal results of 1934, 1935, and 1936, showing the effect of artificial and natural infestation of the soil on number of plants emerged, degree of root-rot infection, and yield, are summarised in Table 17.

From Table 17 it is evident that positive attacks of root rot of oats were produced by artificial infestation of the plots with *F. culmorum*. The effectiveness of the method used to infest field plots is established with a high degree of probability. The mean differences in number of plants emerged, disease rating, and yield between artificially and naturally-

TABLE 17.—EFFECT OF ARTIFICIAL INFESTATION OF THE SOIL WITH *Fusarium culmorum* ON PLANT EMERGENCE, INCIDENCE OF ROOT ROT, AND YIELD IN OATS VARIETAL TESTS, WINNIPEG, 1934–36

Soil treatment	1934	1935	1936
	Percentage of plants emerged*		
Artificially infested with *F. culmorum*	37.2	45.9	57.2
Control (natural soil)	72.6	72.8	67.6
Decrease due to *F. culmorum*	35.4	26.9	10.4
Standard error	±1.45	±0.96	±1.10
	Disease rating*		
Artificially infested with *F. culmorum*	60.3	71.3	61.9
Control (natural soil)	28.3	53.4	54.8
Increase due to *F. culmorum*	32.0	17.9	7.1
Standard error	±1.04	±0.80	±0.75
	Yield (bus. per acre)*		
Artificially infested with *F. culmorum*	51.5	25.0	52.9
Control (natural soil)	78.7	32.8	55.4
Decrease due to *F. culmorum*	27.2	7.8	2.5
Standard error	±1.63	±1.23	±0.69

* Each value represents the general mean of 10 varieties. There were 40 plots of each soil treatment in 1934 and 1935 and 60 plots of each in 1936.

infested plots were very great in 1934. These results with oats confirm those of the wheat-varietal tests and show that plant emergence was reduced, disease infection increased, and yield decreased when the soil was artificially infested with *F. culmorum*.

The magnitude of the mean squares for varieties in relation to the mean squares for error (Table 16), indicates that the oat varieties tested are not genetically similar in their reaction to root-rot caused by *F. culmorum*. The differences observed in the susceptibility of these varieties, based on the varietal means for 1934, 1935, and 1936, are shown in Table 18.

It will be noted in Table 18 that the varieties Victoria and Ohio, and the rust-resistant selection Hajira × Banner (S.13) were most resistant to root rot, while the standard varieties Banner and Victory were most susceptible. It is evident from the results that oat varieties vary considerably in their reaction to root rot.

TABLE 18.—SUSCEPTIBILITY OF STANDARD AND RUST-RESISTANT VARIETIES OF OATS TO ROOT-ROT. AVERAGE RESULTS OF TESTS MADE IN NATURAL SOIL AND IN SOIL ARTIFICIALLY INFESTED WITH *Fusarium culmorum* IN 1934, 1935, AND 1936

Variety	Station No.	Percentage of plants emerged*			Disease rating*		
		Kind of soil infestation					
		Natural	Artificial	Mean	Natural	Artificial	Mean
Victoria	1006	76.8	56.8	66.8	30.0	46.3	38.2
Ohio	105	68.8	60.8	64.8	36.1	42 1	39.1
Hajira × Banner	S.13	74.5	49.1	61.8	34.4	52.9	43.7
Joanette	561	69.0	46.4	57.7	34.1	53.4	43.8
White Russian	177	71.1	46.4	58.8	34.5	54.4	44.4
Hajira × Banner	S.553	71.8	49 6	60.7	36.6	52.1	44.4
Hajira	559	64.1	50.1	57.1	40.2	51.9	46.1
Hajira × Banner	S.339	69 5	44.2	56.8	36.6	56.7	46.7
Victory	159	72 1	38 2	55.2	33.8	59.6	46.7
Banner	179	68 2	40.3	54.2	37.8	57 4	47.6
Mean of soil treatments†		70 6	48 2	59.4	35.4	52.7	44.1
Standard error of varieties		±2 26	±2 26	±1.60	±2 01	±2.01	±1.44

* Each value is the mean of replicated tests of 1934, 1935 and 1936. Varieties arranged in order of resistance according to disease rating.

†Standard error of mean of soil treatments: Percentage of plants emerged = ±0.66; Disease rating = ±0.49.

An examination of the analyses in Table 16 shows that the number of plants emerged and the degree of root-rot infection on oat varieties varied from year to year. This is established by the significant mean squares for years as compared with those for error. These results suggest that environmental factors, affecting as they do the growth of the pathogen as well as that of the plant, cause rather wide fluctuations in the severity of root-rot infection on individual oat varieties from season to season. From Table 16 it will be further observed that the interaction of varieties and years, both for plant emergence and disease rating, is quite significant. Thus further evidence is produced to show the importance of testing the reactions of oat varieties to root rot over a period of years rather than in a single season. These results with oats are essentially similar to those obtained in tests to determine the susceptibility of varieties of wheat to root rot.

The mean squares obtained for the interaction of soil treatments and years compared with those obtained for error are very significant (Table 16). This establishes that the effect of soil infestation with *F. culmorum* varied in different years. From the results in Table 17 it would appear that the seasonal conditions of 1934 were more favourable for the development of *F. culmorum* on oats than were those of 1935 and 1936.

The increase in root rot that may be expected due to artificial infestation of the soil with *F. culmorum* is dependent, to some extent at least, on the varieties used. This is demonstrated, both in respect to plant emergence and disease rating, by the significant mean squares obtained for the interaction of soil treatments and varieties (Table 16). That is, the varietal differences were not the same under the two conditions of plot treatment,

namely, artificial and natural infestation. Hence it would appear that the differential effect of artificial infestation of the soil on resistant and susceptible varieties was not consistent for the three years of the test. The nature of the conditions that bring about these differential responses is not at present clear.

SUMMARY

During the 7-year period 1930–36, several standard varieties and a large number of rust-resistant selections of spring wheat were tested for resistance to root-rot caused by *Fusarium culmorum* and *Helminthosporium sativum*. In 1934, 1935, and 1936 field studies were made to determine the relative susceptibility of ten standard varieties and rust-resistant strains of oats to root-rot caused by *Fusarium culmorum*.

A statistical study of the disease and yield data of several experiments indicated that the disease-rating method of recording the intensity of root-rot caused by *F. culmorum* and *H. sativum* in wheat gives a reliable index of the amount of injury caused by this disease in the field. The results established that the disease rating was significantly negatively associated with yield. It was therefore considered that this method of recording disease intensity was sufficiently accurate to be used as an indication of the reaction of varieties and selections of wheat and of oats to root-rot under field conditions.

Positive attacks of root-rot of wheat and of oats were obtained each year when *F. culmorum* was introduced into the soil. The methods used to establish successful epidemics with this fungus in field plots are described in detail.

Tests made each year during the 3-year period 1934–36, with a large number of wheat varieties, indicated that germinability, or rather the ability of the grain of wheat varieties to produce young plants, varied greatly under field conditions in Manitoba. Germinability was shown to be highest in the varieties and selections that were most resistant to root-rot, and lowest in the most susceptible ones. This result emphasized the importance of this character in the improvement of wheat varieties.

All the standard varieties as well as most of the rust-resistant selections of wheat tested in the course of the investigation, proved to be quite markedly susceptible to *Fusarium-Helminthosporium* root rot. In any given year there were, however, significant differences between varieties of wheat in their reaction to this disease.

The variety Mindum and a few selections with Mindum parentage were most susceptible to root-rot, while a few of the new rust-resistant selections, particularly Apex and Thatcher, proved to be the most resistant. From the results of extensive varietal tests made during the 3-year period 1934–36, it would appear that, in the process of breeding and selecting for rust-resistance in wheat, some slight progress has been made in securing resistance to root rot.

In general, the results established that, in any given year, wheat varieties susceptible to root rot caused by *F. culmorum* were, even when grown under a wide range of field conditions, consistently susceptible to this fungus; while the most resistant varieties were consistently the most

resistant. Moreover, it was found that wheat varieties most resistant to *F. culmorum* were fairly consistently resistant to *H. sativum*, while susceptibility to one of these fungi was significantly associated with susceptibility to the other.

Tests made in 1934, 1935, and 1936 demonstrated that there is a significant variation in the reaction of oat varieties to root-rot caused by *F. culmorum*. The varieties Ohio and Victoria and the rust-resistant hybrid Hajira × Banner (Selection 13) were most resistant, while the standard varieties Victory and Banner were, of the ten varieties and selections tested, most susceptible.

ACKNOWLEDGMENTS

The writers wish to thank Dr. C. H. Goulden and Mr. J. N. Welsh of the Cereal Division, Dominion Rust Research Laboratory, Winnipeg, Manitoba, for their generous co-operation in providing seed of the varieties and strains of wheat and oats used in this investigation. Their further thanks are due to Dr. C. H. Goulden for advice on designing the field experiments and analysing the results.

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CONTROL OF SNAPDRAGON RUST (*PUCCINIA ANTIRRHINI* D. & W.)

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[Received for publication February 1, 1938]

Copper-containing sprays proved more satisfactory than sulphur treatments as preventatives of snapdragon rust on Vancouver Island. This supports the recent investigation of Green (2) in England, but is contrary to the common belief that sulphur compounds are superior to copper as rust preventives and to the recommendations for snapdragon rust control of Butler (1), White (4), Tilford (5), Neis (3), and others.

Rust has reduced seed yield and lowered the ornamental value of snapdragons in the coastal area of British Columbia for many years. Complete failures have been reported by some of the seed growers.

This paper gives the relative value of different copper and sulphur sprays as preventives of snapdragon rust at Victoria, British Columbia.

MATERIALS AND METHODS

Spray materials used in this snapdragon rust experiment are listed in Tables 1 and 2. The rust appeared too late in 1934 and 1935 to justify taking the data. In 1936 the plots were sprayed on July 7 and 17 and in 1937 on June 30 and July 22. Great care was taken to get a coverage of the spray on the underside of the leaves as well as on top. The approximate quantity of spray required for one acre was 160 gallons, which made the cost of the spray material, Bordeaux 4–4–40 plus agral 2, less than $2.50 per acre for each application. Two men with barrel pump sprayed an acre in two days.

Each plot, which was replicated, consisted of 5 rows, 18 inches apart by 12 feet, and contained 60 plants.

The amount of copper was approximately the same in the following sprays applied in 1937: Bordeaux, Burgundy, Bouisol, Copper hydro and Micronised Burgundy.

Volunteer and other snapdragon plants have been destroyed before spring since 1933 on the seed farm where the investigation was conducted.

The data were taken on September 23 and 14, 1936 and 1937 respectively.

RESULTS

Bordeaux 4–4–40 plus a spreader like agral 2, applied to give coverage on the underside of the leaves, as well as on top, was an effective preventive of snapdragon rust (Table 1 and 2) and Plate 1. Only two applications of Bordeaux plus a spreader were necessary in 1936 and 1937 to protect the seed crop. The Bordeaux mixture used in these experiments was different from that used by Green (2) in that quicklime was used instead of hydrated lime and the strength was increased from 4–5–50 to 4–4–40. Green found Burgundy the best in England, while Bordeaux appears definitely superior at the Coastal areas of British Columbia. Although

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PLATE I

1.

2.

3.

4.

PLATE I. Snapdragon foliage. 1. Sprayed twice with bordeaux 4-4-40. 2. Sprayed twice with lime-sulphur 1-50. 3. Sprayed twice with bordeaux 4-4-40 plus a spreader. 4. Unsprayed.

TABLE 1.—THE EFFECT OF DIFFERENT SPRAYS ON THE AMOUNT OF SNAPDRAGON RUST IN 1936

Treatment*	Amount of leaf area rusted
	%
Check	62.5
K.S. Resin 1 lb. to 10 gals.	49.6
Lime sulphur 1–50 plus penetrol	45.7
Lime sulphur 1–50 plus lethelate	65.0
Bordeaux 4–4–40	13.4
Bordeaux plus penetrol	0.7
Bordeaux plus lethelate	0.8
Bouisol 2 pints per 100 gals. plus penetrol	23.4

* Spreaders were used at the following strength per 100 gals. of spray: Agral 2—1 lb.; Lethelate—1 pint; Penetrol—2 quarts.

TABLE 2.—THE EFFECT OF DIFFERENT SPRAYS ON THE AMOUNT OF SNAPDRAGON RUST IN 1937

Treatment*	Amount of leaf area rusted
	%
Check	71.8
Lime Sulphur 1–50 plus agral 2	30 5
Bordeaux 4–4–40	10.5
Bordeaux 4–4–40 plus agral 2	2.1
Bordinette 1 lb. to 10 gals. plus agral 2	12.2
Bouisol 1 and ¾ lbs. to 10 gals. plus agral 2	7.8
Burgundy 4–5–40 plus agral 2	14.5
Copper hydro 1 lb. to 10 gals. plus agral 2	12.2
Micronised Burgundy 1¼ lbs. to 10 gals plus agral 2	23.6

* Spreaders were used at the following strength per 100 gals. of spray: Agral 2—1 lb.

Bordeaux with a spreader was more effective than other copper sprays for the control of snapdragon rust, it discolours the foliage and hence cannot be recommended when snapdragons are grown for ornamental purposes. Consequently, we agree with Green that copper sprays are more effective than sulphur sprays.

The following copper sprays with a spreader gave sufficient protection from rust on snapdragons grown for seed to warrant trial on ornamental snapdragons: Bouisol 1 pint to 10 gallons of water; Bordinette 1 pound per 10 gallons; Burgundy 4–5–40; and Copper hydro 1 pound to 10 gallons. By increasing the strength of Bouisol from 1 pint to 50 gallons of water in 1936 to 1 pint to 10 gallons in 1937, the effectiveness of the spray was improved.

Spraying after the flowers begin to open was not necessary to protect snapdragons grown for seed. The increase in number and growth of leaves was small after flowering began. Further evidence of the effectiveness of Bordeaux 4–4–40 plus agral 2 is indicated from the results obtained by a seed grower who sprayed 25,000 plants twice in July and left 120 plants

unsprayed. The sprayed plants gave a normal crop of seed, while the unsprayed were nearly a complete failure.

Spreaders agral 2, Lethelate and Penetrol increased the efficacy of Bordeaux.

Burning of volunteer and other snapdragon plants before spring since 1933 may account for the late appearance of rust in 1934, 1935, 1936 and 1937. The earliest date that rust was observed in 1934, 1935, 1936 and 1937 was on July 29, 1937. Previously rust was commonly observed in June and sometimes in May.

SUMMARY

1. Copper sprays are more effective than sulphur in the control of snapdragon rust in the coastal areas of British Columbia.

2. Bordeaux 4–4–40 plus a spreader, agral 2, lethelate, or penetrol, is an effective preventive of rust in snapdragons grown for seed.

3. Only two applications of Bordeaux plus a spreader were necessary in 1936 and 1937 to protect the seed crop.

4. Spraying after the flowers begin to open is not necessary in the case of plants grown for seed.

5. Spreaders agral 2, lethelate and penetrol improve the efficacy of Bordeaux.

6. The following copper sprays plus agral 2 gave sufficient protection from rust on snapdragons grown for seed to warrant their trial on ornamental snapdragons: Bouisol 1 pint to 10 gals. of water, Bordinette 1 lb. to 10 gals. of water, Copper hydro 1 lb. to 10 gals of water and Burgundy 4–5–40.

7. Burning of volunteer and other snapdragon plants before spring since 1933 may account for the late appearance of rust in 1934 to 1937, inclusive.

ACKNOWLEDGMENTS

The author wishes to thank Mr. J. W. Eastham and Dr. W. Newton for reading the manuscript, Mr. H. Edwards for the photographs and Mr. G. A. Robinson for the use of his plantings for trial work.

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OAT NEMATODES ON WINTER WHEAT

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[Received for publication January 6, 1938]

During the summer seasons of 1933–34, when the previously reported investigations (2) on the disease of cereals caused by the oat nematode *Heterodera schachtii* Schm. were being conducted in South Simcoe county, it was found that winter wheat was also a host of this parasite. It was observed at that time that the nematodes did attack winter wheat, and that they could complete their life cycle in the wheat roots; but no cases of severe damage to the wheat crop, traceable to nematode infestation, were encountered in the course of a detailed survey of the grain fields of the district. However, in the spring of 1937, our attention was drawn to three fields of winter wheat in the infested area which were obviously unhealthy, and they were kept under observation during the season. One of these fields was plowed up as a crop failure, while the diseased portions (about 75%) of the other two fields, were not worth cutting. Detailed examination established the fact that the roots of the plants in these areas were more heavily infested with nematodes than any winter wheat roots previous observed. It is the purpose of this communication, therefore, to record these instances of crop failure and to provide a brief description of the effects of this disease upon winter wheat.

The upper parts of the infested plants are stunted, and support very small, poorly-filled heads. The root systems show the characteristic bushy appearance and local thickening previously described in detail for oats (2). A comparison of diseased and healthy root systems of winter wheat of the variety Dawson's Golden Chaff is seen in Figure 1. It is notable that wheat roots, even more than oat roots, exhibit the local swellings from which emanate bunches of rootlets as depicted in Figure 2. When maturing, the female nematodes may readily be seen with the naked eye, as they appear on the outside of the roots.

It must not be concluded, however, that all fields of winter wheat, sown on sites that are heavily infested with oat nematodes, will result in crop failure. Cases to the contrary are easily found, and it is not clear why these particular fields were so badly damaged. Since the crop was not seen in the early stages, it is impossible to state whether the injury occurred in the spring or in the previous fall, but it is worth mentioning that all three fields were sown unusually early, having been seeded August 28 to September 1. The early seeding would permit a maximum of infestation to take place in the early autumn and this may, in part, account for the extraordinary amount of damage experienced. The intervening winter was also very mild, hence it may have been a more complex set of conditions which combined to favour the progress of the nematodes. Finally, there is the possibility of the development of a physiological race which is adapted to winter wheat. Goodey (1), in reviewing the question of biologic races,

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cites evidence to show that the oat race of *H. schachtii* Schm. is not homogeneous, and that further segregation may take place. Further study is therefore required before any more definite interpretation can be advanced concerning the causes of the outbreak.

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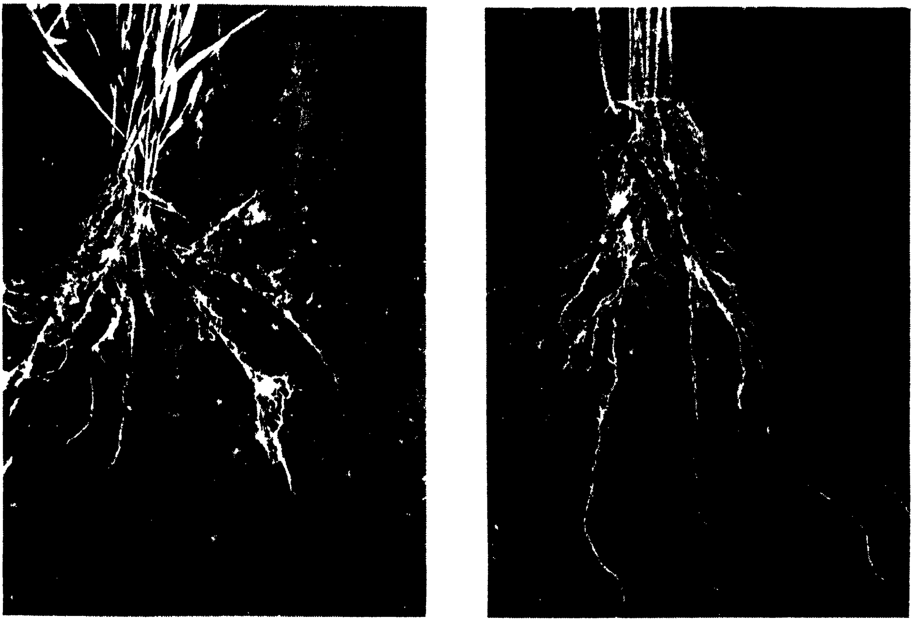

FIGURE 1 A comparison of diseased (left) and healthy (right) root systems of winter wheat

FIGURE 2 Roots of winter wheat, infested with nematodes.

OAT NEMATODES ON WINTER WHEAT—CHAPMAN

THE CONTROL OF THE GREENHOUSE WHITEFLY IN CANADA BY THE PARASITE *ENCARSIA FORMOSA* GAHAN

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[Received for publication February 21, 1938]

INTRODUCTION

The greenhouse whitefly *Trialeurodes vaporariorum* Westw. is one of the most common pests of greenhouse crops. Satisfactory artificial control is difficult, due to the inability of most poison sprays, dusts, or fumigants to kill all stages of the insect. The results of investigations and observations at the Dominion Parasite Laboratory during the past 9 years have shown that the greenhouse whitefly can be controlled by the parasite *Encarsia formosa* Gahan. The investigations have also shown that the control of greenhouse insects by parasites is a specialized field of biological control. Many factors that complicate the attempted control of insects in the field, such as temperature, humidity and rate of dispersal, can be controlled under greenhouse conditions. One factor, however, that is not usually important in the field is of extreme importance when attempting to control greenhouse insects by biological methods. That is, the fact that frequently an insect pest must be controlled before the crop on which it is feeding is marketed, whereas in the field the time factor is not so important. To be successful under greenhouse conditions, a parasite must have the ability to increase rapidly and to control its host quickly. Even the most prolific parasite cannot be expected to control in a few weeks a pest that is present in large numbers. For this reason, the control of greenhouse insects by parasites is dependent upon the introduction of the parasites before a heavy infestation of the pest has developed, or where, as is the case with *Encarsia formosa*, the parasites can be used in conjunction with artificial control methods.

HISTORY OF THE PARASITE

The country of origin of *Encarsia formosa* is not known, but since it cannot survive extremes of either heat or cold it is probably of semitropical origin.

This chalcid parasite of the family APHELINIDAE was first recorded in 1924, when specimens taken in the United States from Ohio were described by Gahan. Two years later (1926) it was found in a small greenhouse in England. Parasitized scales were sent to the Cheshunt Experiment Station where the life-history and habits were studied, and where technique for distribution under English conditions was developed by Speyer (1, 2). The desirability of obtaining the parasite from England was discussed in 1928 with Sir Guy Marchall, Director of the Imperial Institute of Entomology, by Dr. Arthur Gibson, Dominion Entomologist. Soon afterwards, Dr. W. R. Thompson, in that year appointed as Superintendent of

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the Farnham House Laboratory, obtained from Mr. E. R. Speyer, a supply of the parasite, which was forwarded to Canada. Distribution has also been made through Farnham House Laboratory to other parts of the British Empire. Following the receipt of the parasites in Canada, a survey made by Mr. A. B. Baird showed that the species was already present in a number of greenhouses. Establishment of the parasite in the Channel Islands was secured in 1928. Several unsuccessful attempts were made to secure its establishment in Australia and New Zealand. However, in 1934, Muggeridge (3) reported the establishment and distribution of the parasite in New Zealand. In 1936 it was introduced into Australia from New Zealand. Finally Tannoir (4) reported its establishment in Tasmania. A species of *Encarsia*, probably *formosa*, was reported by Weber (5) attacking *Trialeurodes vaporariorum* in Germany.

The rapid establishment and distribution of this parasite are largely due to the fact that it reproduces parthenogenetically. Although a small percentage of males are produced, they are not necessary for reproduction and appear to be impotent. This method of reproduction, and the fact that there have been no secondary parasites recorded in Canada, gives the parasite a decided advantage over the host insect, and increases its effectiveness. Its effectiveness is recognized by commercial greenhouse men, many of whom have expressed the opinion that it provides an excellent means of supplementing and, under certain conditions, substituting for artificial methods of control. Some of the weak points in artificial control of the pest are listed below:

1. Cyanide, which may be cited as representative of the "gas" method of control, is effective, if properly used, in killing the adults of the pest but usually does not kill more than 80% of the immature stages.

2. Greenhouses that are not reasonably airtight are unsuitable for fumigation, due to air movement which causes unequal distribution of the gas, and results in an unsatisfactory kill in some sections and a possibility of burning of the plants in others.

3. Many greenhouse men produce several varieties of plants in the same house and often one or more varieties are susceptible to gas injury and, therefore, cannot be fumigated.

4. Fumigation is unsafe in any greenhouse or conservatory which is attached to a dwelling.

5. Many large ranges of greenhouses cannot be divided easily; for this reason it is difficult to control by fumigation an infestation in one or two small areas.

6. The personal factor is important. Many operators use too strong or too weak a concentration of gas, and either the plants are injured or an unsatisfactory kill results.

7. If an insecticide in the form of a spray or dust is used, the immature stages of the whitefly can be killed if all leaf surface is completely covered. This is very difficult to do with many varieties of plants such as primulas. Even with complete leaf coverage many adults escape and continue the infestation.

PRODUCTION

Summer Rearing

It has been found that after rearing from 7 to 9 generations of the host and parasite in a greenhouse through the autumn, winter, and spring months, more satisfactory results the following year can be expected if a few generations are reared out of doors during the summer. Colonies of both host and parasite are transferred from the greenhouse to the garden in June. If proper conditions and suitable host plants are provided, the insects propagate and increase with very little attention. In autumn, the exact time being dependent upon weather conditions, young tomato plants growing in cold frames are artificially infested with adult whiteflies. After about two weeks, the parasites are introduced. When there is a possibility of frost the infested plants are moved into the greenhouse. In this way a vigorous supply of host plants, host insects and parasites is provided for winter propagation each year.

During the summer, shade, other than that provided by the host plant, is necessary at extremely high temperatures, particularly if the humidity and soil moisture is low. Unsuitable conditions are indicated by the wilting of the host plants. The effect is probably secondary. Transpiration is greatly reduced when wilting occurs, which results in an increase in the temperature of the leaf surface and a decrease in the relative humidity to a point that is lethal to the larval and pupal stages of the host insect. This condition can be prevented by planting the host plants under trees or in the shade of buildings.

The following host plants, listed in order of suitability, have been used for summer propagation: tobacco, (cigar leaf type), tomato, squash, morning glory, hollyhock, bean, and egg plant. Suitability is determined by host and parasite preference, and freedom of the host plant from attack by other insects.

Winter Rearing

The period when the parasites are reared in the greenhouse (from September to June) corresponds with the period of greatest activity in commercial greenhouses. During the entire period a surplus is maintained to supply requests from growers. To do this there must be at all times sufficient healthy host plants in the proper stage of development for infestation. Tobacco and tomato seed is planted about July 10, and at frequent intervals throughout the season. Seed germination and plant growth is slow and uncertain during October, November, December and early January, and to provide suitable plants during those months, seed is planted at 2-week intervals. Later in the season when growing conditions are more satisfactory, seed is sown at intervals of 4 weeks.

Production of Disease-free Host Plants

The parasites are shipped in the pupal stage on the host plant leaves; it is, therefore, essential to produce only healthy plants. Seed selection is important, since both tomato and tobacco seed may carry the organisms of virus diseases. Fortunately it has been possible to secure disease-free seed from the St. Catharines Plant Pathology Laboratory, through Dr. Berkeley, the officer-in-charge. Dr. Berkeley has also kindly provided a

simple method of determining the presence of virus disease in growing plants. By this method infected plants can be detected and destroyed as soon as suspicious symptoms are noted.

Artificial Light

Artificial light was tested for a period of three years. Lights of intensities varying from 25 to 100 watts were suspended at different distances from the growing plants. The results may be summarized as follows:

Host Plants: Tomatoes produced more suitable foliage during late autumn and early winter. Tobacco was brought into bloom earlier and matured more rapidly (an unsatisfactory condition).

Host Insects and Parasites: The proportion of parasites increased slightly when 100-watt lights were used. This may have been due to a slight increase in temperature caused by the heat from the lights. Lights of each intensity used attracted both whiteflies and parasites, and large numbers were killed. For this reason artificial light has been discontinued.

Temperature

Temperature is probably the most important single factor in the production of *Encarsia formosa*. It is by the regulation of temperature and the proportion of tomatoes and tobacco, which will be discussed later, that the required number and the proper proportion of hosts and parasites are maintained. The general effect of temperature was worked out by Speyer. To state it briefly, high temperatures favour the increase of the parasite and low temperatures favour the whitefly. In Canada it has been found that if the mean temperature is between 50° and 60° F., the whitefly can be expected to increase. Between 60° and 75° the proportion of parasites increases. A mean temperature below 50° or above 75° is unsuitable for either host or parasite. Temperature must also be considered from the point of view of host plant propagation. During autumn and early winter, usually from October through January, a comparatively low temperature is necessary for satisfactory plant growth. A high temperature produces rapid soft growth that breaks down quickly when subjected to heavy insect infestation. It has been found that a night temperature of 58°, supplemented by a day temperature of 60° or over, depending upon the intensity and amount of sunlight, is satisfactory for plant growth and parasite development. After January, the temperature may be raised to a mean of 65° or slightly higher.

Temperature is also important in its effect on the length of life cycle. Investigations both in Canada and England have shown that the average time required to complete the life cycle from egg to adult is from 28 to 30 days; the period may be shorter or very much longer, depending upon the temperature. Although hibernation has not been induced, development in the late larval and pupal stages is retarded by storage, at low temperatures, as shown in Table 1.

The ability of the parasite to withstand a period of 3 or 4 weeks of storage at 42° F., is as indicated in Table 1, is useful in maintaining a supply between crops. It is in the period between the time when one crop

TABLE 1.—RESULTS OF STORAGE OF *Encarsia* IN THE LATE LARVAL, AND PUPAL STAGES

Period of storage	Temperature	Percent emergence	Average period from egg to adult
18 hours	12° F.	51	29 days
18 hours	20	88	30 days
7 days	42	95	34 days
14 days	42	86	40 days
21 days	42	55.5	45 days
28 days	42	22	51 days
35 days	42	0	—
*0		91.8	28 days

* Check lot reared through to emergence at room temperatures, 60° to 70° F., without any storage period.

is removed and the next one is planted that the parasite population is often greatly reduced or lost entirely. If parasite material is placed in storage during this period, it is much easier to maintain a continuous supply.

The average emergence of parasites from all material used for storage (2000) was 77%, while the emergence of whiteflies under the same conditions was 6%. The parasite is apparently better able to withstand the reduction in moisture, due to the drying out of the leaves after removal from the host plant.

Humidity

It is difficult to measure the humidity requirements of *Encarsia formosa*. The immature stages are not affected except through the host. An emergence of 100% adults has been secured at relative humidities ranging from 30% to more than 80%. Adults are more susceptible to humidity, and the length of adult life is considerably shortened by low humidity.

Host Plants

Investigations to date indicate that no species of plant is absolutely repellent to the parasite. Speyer, in developing rearing technique, found that tobacco was repellent to *Encarsia* and could be used to advantage in maintaining the supply of host insects. The results at the Dominion Parasite Laboratory have been somewhat contradictory. The parasitism on tobacco has fluctuated markedly from year to year, but has been consistently higher on the broad leaf cigar type tobacco than on the narrow leaf flue cure type. The degree of preference for host plants exhibited by both host and parasite shows great variation, even within the same species of plant. The reason for this preference is not known.

Parasitism of whitefly by *Encarsia formosa* has been secured in varying degrees on a large number of weeds, and the following vegetables and flowers: tomato, bean, squash, pumpkin, cucumber, egg plant, tobacco, potato, lettuce; fuchsia, pelargonium, primula, aster, salvia, lantana, petunia, poinsettia, coleus, variegated maple, gardenia, geranium, calcoelaria, morning glory, and hollyhock.

DISTRIBUTION TO GROWERS

Encarsia formosa is distributed in the pupal stage. Infested leaves are removed from the host plants and examined. Whitefly scales that are not parasitized are destroyed with dissecting needles. The leaves are

placed in waxed paper and then rolled in bundles to fit cardboard tubes, each of which contains from 1000 to 5000 parasite pupae. The tubes are wrapped with ordinary wrapping paper and shipped by parcel post. A mimeographed sheet of directions is enclosed with each shipment to ensure proper handling of the material by the grower who receives it. This method of distribution has proven satisfactory, and shipments have been made to all parts of Canada with excellent results.

The number of parasites required to control an infestation is determined from a consideration of all the information available. To obtain the best results, it is necessary to know: the area under glass, area infested, crops infested, degree of infestation, stage of development of the crops, and the temperature at which the crops are grown.

(1) The Area Under Glass.—This information is used for purposes of record and is necessary because it has been found that larger areas require proportionately fewer parasites than do smaller areas.

(2) Area Infested.—The number of parasites required for control on a given crop is based upon the number of square feet of infested area.

(3) Crops Infested.—Some crops require more parasites than others. For example, two greenhouses each with an area of 1,000 square feet are planted with tomatoes and primulas respectively:

	No. 1	*No. 2*
Area	1,000 sq. ft.	1,000 sq. ft.
Crop	Tomatoes	Primulas
No. of plants	500	5,700
No. of whiteflies per plant	3	3
Total no. of whiteflies	1,500	17,100

Given the same population of whiteflies per plant, the total population increases proportionately with the number and size of plants infested.

A knowledge of the crops infested is important also because, if several crops are present, the parasites occasionally show a host plant preference, and unless a large parasite population is present, satisfactory control of the pest is not secured.

(4) Degree of Infestation.—The degree of infestation is important since it gives an indication of the total population. It also indicates whether the parasites can be expected to control the infestation unassisted. If the infestation is such that it cannot be controlled quickly, a light fumigation to kill the adult whiteflies is advised. The following quotation is taken from the instructions sent out with each shipment of parasites. "In case a severe infestation of whitefly is already present, and fumigation is possible it would be advisable to give a very light fumigation with hydrocyanic acid gas immediately before the parasites are placed in the house. This will kill the majority of the adult whiteflies and leave the young stages of the fly alive for the parasites to breed in."

(5) Stage of Development of the Crops.—A crop that is nearing maturity has a larger population than a new crop and, therefore, requires more parasites.

(6) The Temperature at which the Crops are Grown.—As was stated earlier in this paper, temperature is one of the most important factors in the rearing of *Encarsia*. It is also important in deciding the number of parasites necessary to control an infestation of whitefly. If the temperature is near the optimum, fewer parasites are required than if it is higher or lower.

After a consideration of the above imformation, or as much of it as is available, an estimate is made of the number of parasites required. Usually from 1000 to 2000 parasites per thousand square feet of greenhouse space are sufficient to control an infestation. If more than 3000 parasites per thousand square feet are necessary, better results can be expected if a light fumigation is carried out before the parasites are introduced.

The practical value of this parasite has been demonstrated by its effective control of the whitefly on many varieties of plants and over a wide range of greenhouse conditions. Its use is increasing and should continue to increase as growers become more familiar with its use and possibilities.

In addition to the economy of this method of control it makes possible the growing of certain varieties of susceptible plants under conditions where fumigation or other treatment cannot be carried out, and also the growing of crops that would be severely injured or destroyed by fumigation. Some idea of the increasing use of *Encarsia formosa* may be obtained from the steadily increasing number sent out from the laboratory. In 1935 the shipments amounted to 230,800; in 1936, 326,160; and in 1937, 602,000 parasites. Shipments are made only on the request of growers, and a large portion of the increased demand has come from growers who have used the parasites with success in previous years, and those who have learned of their successful use by others.

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

III. THE FLIGHT OF THE EUROPEAN CORN BORER. THE INFLUENCE OF THE PHYSICAL FACTORS UPON FLIGHT

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[Received for publication January 12, 1938]

(A) Temperature

The Optimal Temperature of Flight

The number of moths flying in plots "A" and "B" during the last ten years are plotted against the temperature at which they were observed in flight in Figure 1. This is done without considering any other factor. Because of the length of observations the data should give a close approximation to the temperature preferred by the moths for flight.

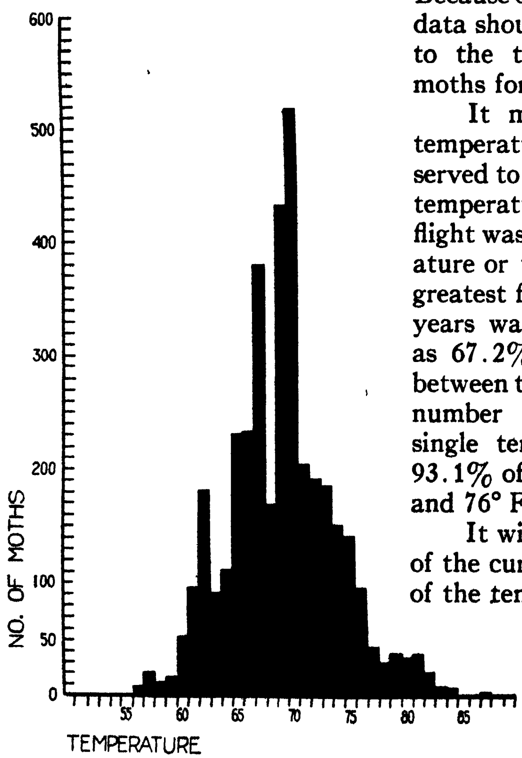

FIGURE 1. Temperature at which flight of moths took place, Plots A and B, Chatham, Ontario, 1927-36.

It may be seen that the lowest temperature at which moths were observed to fly was 56° F., while the highest temperature at which moths were in flight was 87° F. The optimum temperature or the temperature at which the greatest flight activity took place for all years was between 65° F. and 70° F., as 67.2% of all moths observed flew between these temperatures. The largest number of moths observed for any single temperature occurred at 70° F.; 93.1% of all moths flew between 60° F. and 76° F.

It will be noted also from the shape of the curve in Figure 1 that a lowering of the temperature from 65° F. inhibits flight very quickly, while an increase in temperature above 75° F. decreased flight much more gradually. In other words, the moths react more quickly to low temperatures than they do to high temperatures.

[1] Entomologist in charge.

An exploratory histogram of the data as to the temperature at which the individual sexes flew was made and it was found that no difference in the temperature at which males and females fly could be detected. Both sexes have the same general flight temperature relations as shown in Figure 1 in which sexes are combined.

The Graphic Presentation of the Relationship of Flight to Temperature and other Factors

A study of the effects of temperature and other factors in individual years and for individual nights is given below. These effects may be studied more effectively when the factors are plotted upon the same graphs as the flight in the various plots. This is done for each year in charts, Figures 2 to 11. The values for temperature, saturation deficiency, relative humidity and wind, are the average for each night for the duration of evening flight. This is generally the period from 7:30 p.m., to 12:30 a.m., or for the number of observations taken on the particular night. Temperature is in degrees Fahrenheit, saturation deficiency in millimetres of mercury of vapor pressure, and wind is in feet per minute.

The Regulative Action of Temperature upon Flight

A study of Figures 2 to 11 shows a very remarkable correspondence in the variations of the relative number of moths observed in the two field plots and in the light trap from night to night. A more remarkable correlation is seen to exist between the fluctuations in temperature and the fluctuation in the number of moths in each plot or in the light trap. A rise in temperature shows an increase in the number of moths in flight and a decrease in temperature shows a decrease in the number of moths or cessation of flight, if the temperature is low enough. Peaks in moth flight agree with peaks in temperature, while depressions in flight agree with depressions in temperature. There are very few exceptions to this correlation.

A general discussion of temperature and flight in each year follows:

Year 1927. This was a relatively cool year as can be seen by the low position of the temperature curve in relation to its base. Humidity was high, as indicated by the very high position of the relative humidity curve and the relatively low saturation deficiency curve. Wind was relatively low throughout the year. It was probably the least windy of any year at the time of flight, The flight curve agrees well with that of temperature, major peaks of flight occurred at the major peaks of the temperature curve. Moth flight was prohibited on July 19, 29, August 1 and 2, by low temperature.

Year 1928. This was another comparatively cool year during flight as shown by the low position of the temperature curve, although three medium-placed peaks in temperature occurred. Humidity was high as shown by the low saturation deficiency curve. Wind was very low. The peaks and depressions of flight agree with those of temperature except on July 10 when with a fairly high temperature, no moths were secured. The only apparent reason for this discrepancy is the fact that only two hourly records were taken on this night instead of the usual number and the moths did not fly until later in the evening after the observations were made, although moths had flown during the two early observations, before

and after this date. Moth flight was prohibited by low temperature on July 13, 28, 29. There is no discernible reason for their absence on August 1 unless it was the nearness of this date to the termination of flight.

Year 1929. This was an intermediate year in the value of the physical factors. Temperature was fairly low during the beginning of the period, followed by a period in which it was quite high. Relative humidity was generally high as shown by the low saturation deficiency curve. Wind was low except for two peaks. Plots A and B are almost exactly alike in their variations in numbers of moths in flight and both follow the temperature curve very closely. The absence of moths in plot A on July 6 is unexplainable. Five observations were made in the plot. In plot B, on the other hand, two moths were secured. This variation might be due to the comparative earliness of the night in the flight season. Moth flight was prohibited on July 19 and July 20 by low temperature, although one moth was secured in plot B during the first observation hour, when the temperature was 59° F. After this hour, the temperature fell rapidly.

Year 1930. Temperature in this year was fairly high with a very hot period during the latter portion of flight. Humidity was fairly high at first, but low during the period of high temperature. Wind was variable, but moderately high. In general, it was a normal year, with a hot, dry period toward the end of flight. The moth flight curve and that of

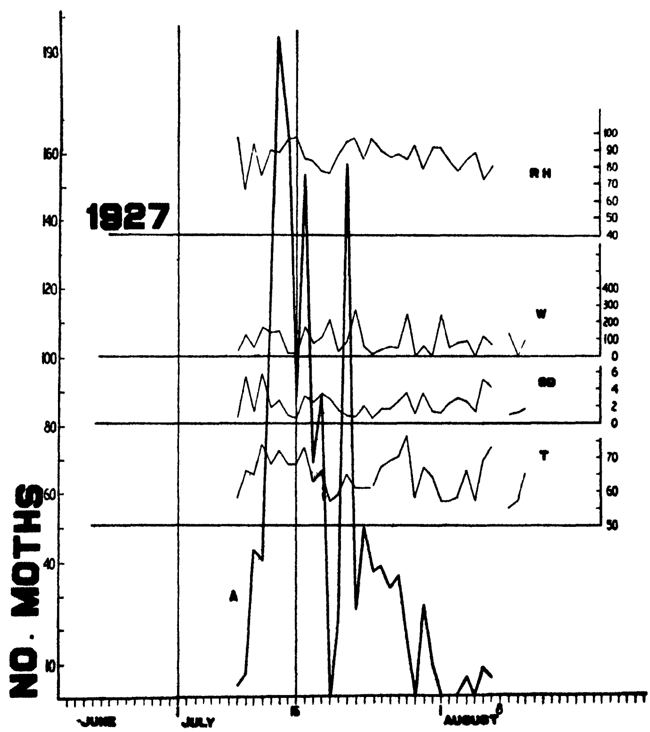

FIGURE 2. Relationship of flight to certain physical factors, Chatham, Ontario, 1927. A—Daily flight of moths, Plot A.

T—Mean temperature, S.D.—Mean saturation deficit, W.—Mean wind velocity, and R.H.—Mean relative humidity, respectively, for daily period of observation.

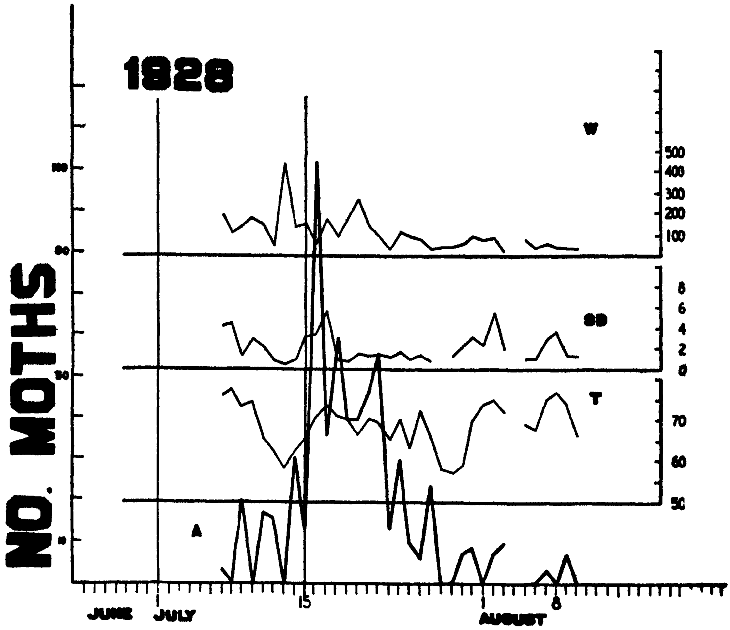

FIGURE 3. Relationship of flight to certain physical factors, Chatham, Ontario, 1928. A—Daily flight of moths, Plot A.

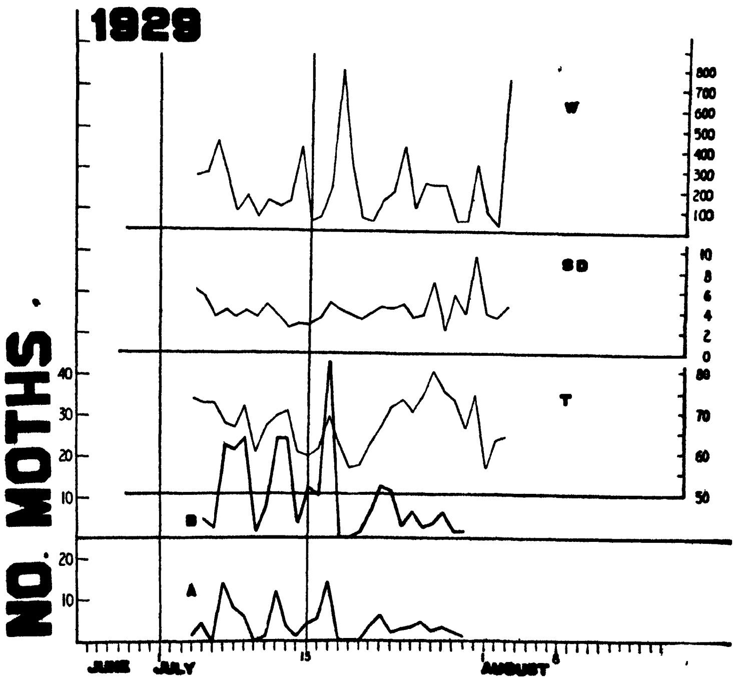

FIGURE 4. Relationship of flight to certain physical factors, Chatham, Ontario 1929. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B.

T.—Mean temperature, S.D.—Mean saturation deficit, and W.—Mean wind velocity, respectively, for daily period of observation.

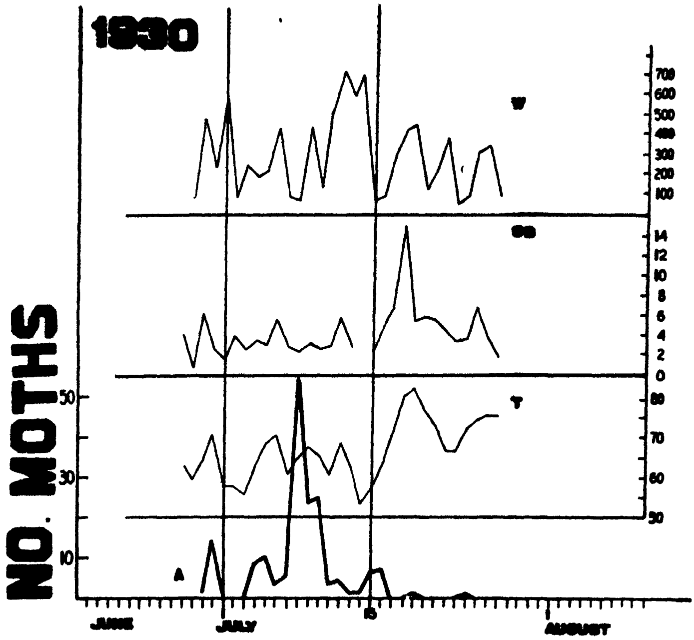

FIGURE 5. Relationship of flight to certain physical factors, Chatham, Ontario, 1930. A—Daily flight of moths, Plot A.

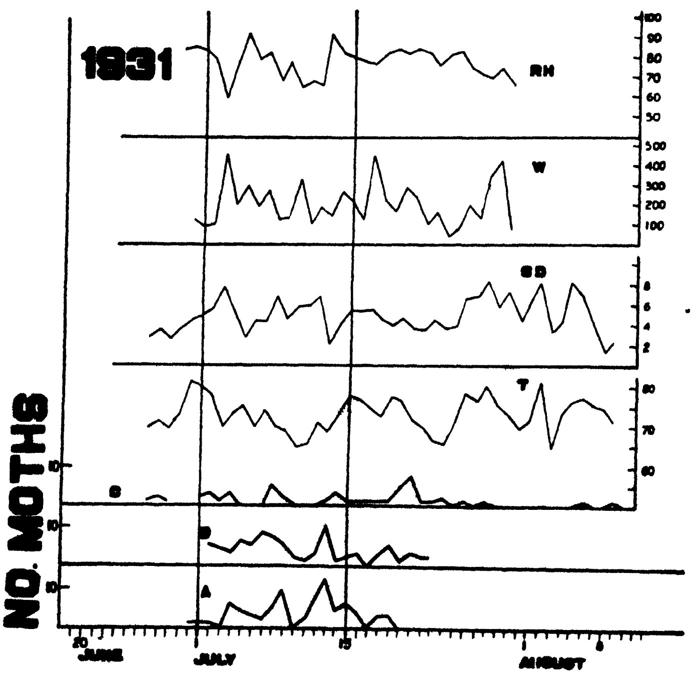

FIGURE 6. Relationship of flight to certain physical factors, Chatham, Ontario, 1931. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, W.—Mean wind velocity, and R.H.—Mean relative humidity, respectively, for daily period of observation.

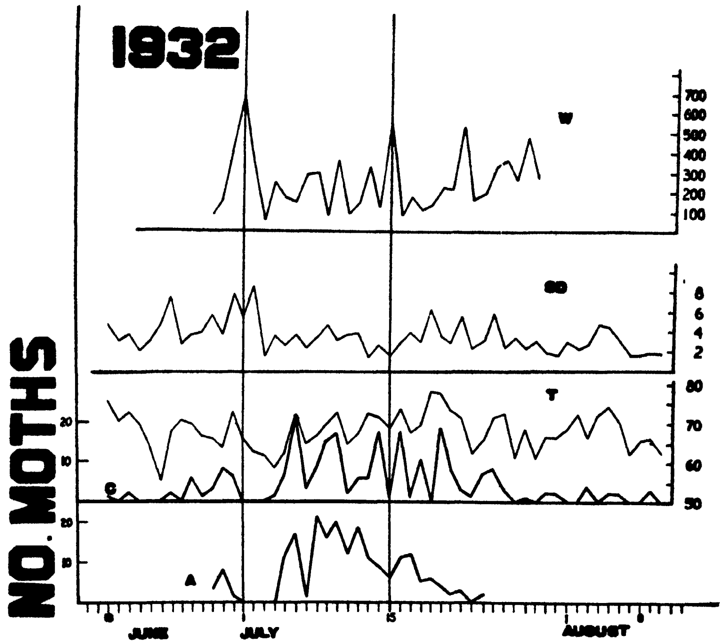

FIGURE 7. Relationship of flight to certain physical factors, Chatham, Ontario, 1932. A—Daily flight of moths, Plot A; C—Dailv flight of moths to light trap.

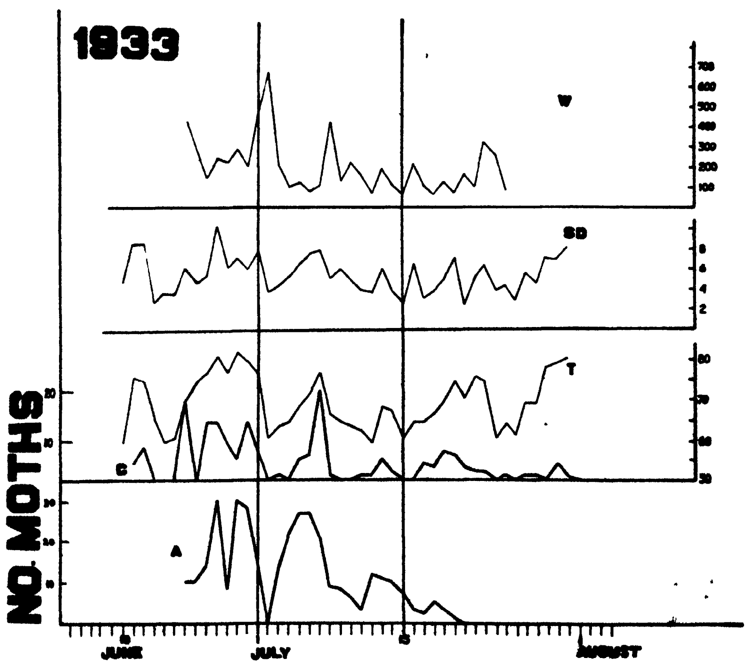

FIGURE 8. Relationship of flight to certain physical factors, Chatham, Ontario, 1933. A—Daily flight of moths, Plot A; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, and W.—Mean wind velocity, respectively, for daily period of observation.

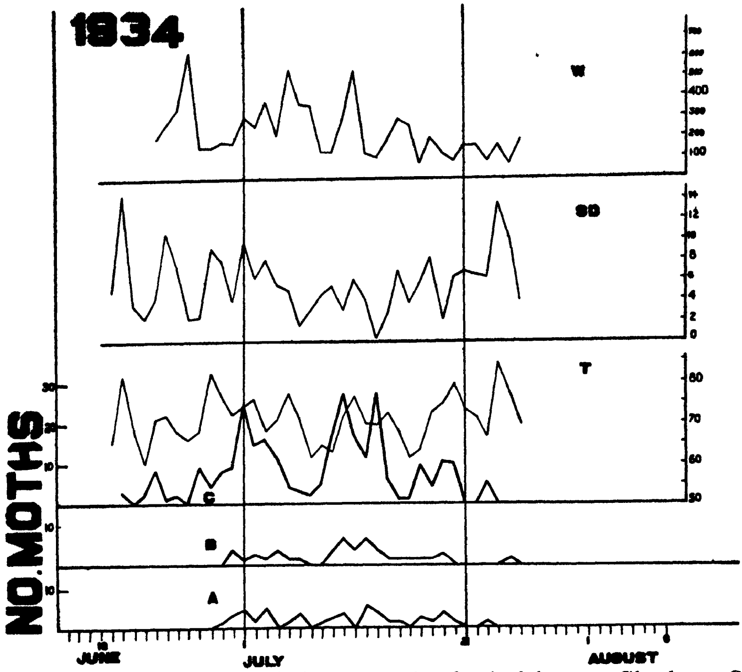

FIGURE 9. Relationship of flight to certain physical factors, Chatham, Ontario, 1934. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B; C—Daily flight of moths to light trap.

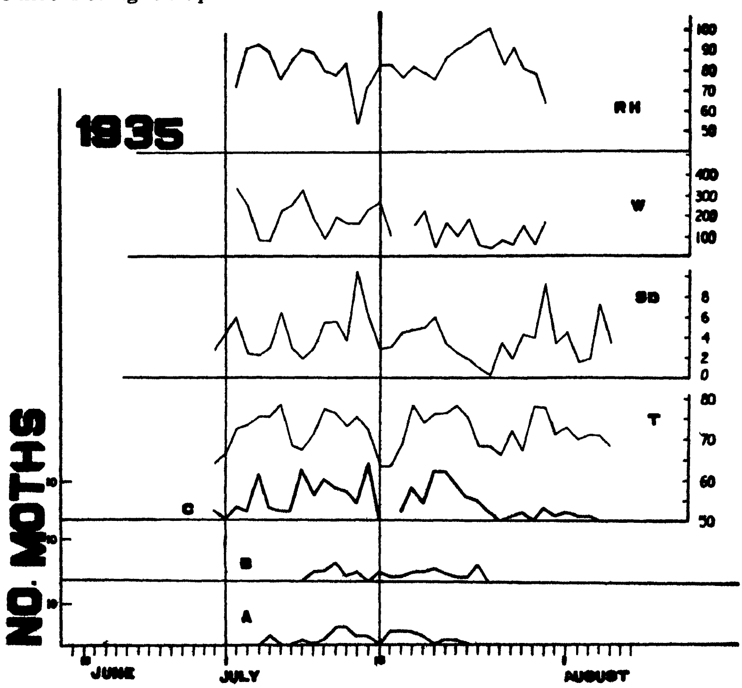

FIGURE 10. Relationship of flight to certain physical factors, Chatham, Ontario, 1935. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, W.—Mean wind velocity, and R.H.—Mean relative humidity, respectively, for daily period of observation.

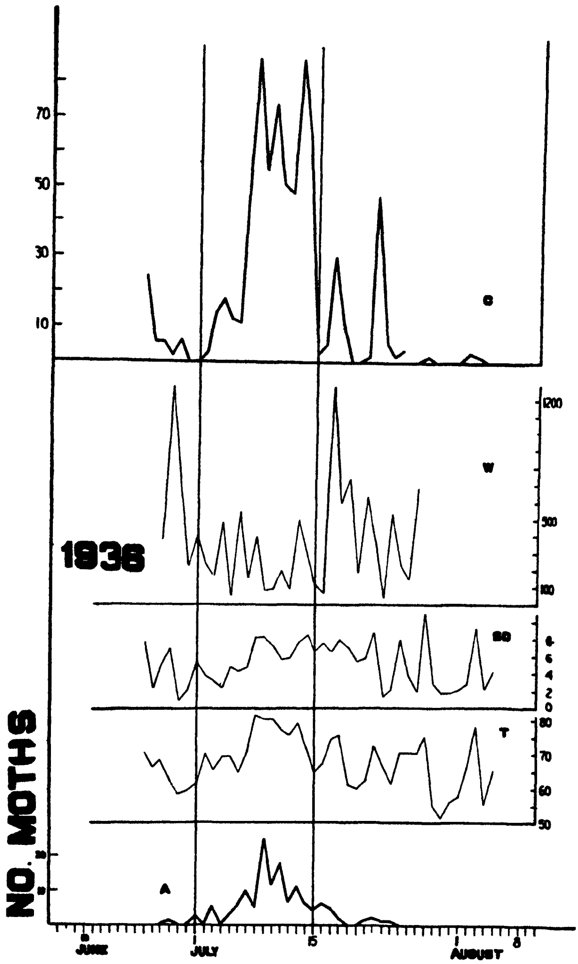

FIGURE 11. Relationship of flight to certain physical factors, Chatham, Ontario, 1936. A— Daily flight of moths, Plot A; C—Daily flight of moths to light trap. T.—Mean temperature, S.D.—Mean saturation deficit, and W.—Mean wind velocity, respectively, for daily period of observation.

temperature agree uniformly, possibly more so than for some of the other years. Moths were absent from the field because of low temperatures on July 1, 2, 3, 14 and 15. On July 18 and 19. the temperature was 80° F. and 82° F. respectively. At time of first observation, July 18, the humidity was very low, but on July 19 it was moderately high. It would appear that perhaps this hot, dry period prohibited flight as moths were taken before and after the period.

Year 1931. This year was characterized by high temperature throughout the period of flight. The humidity was average, but higher than in previous years. Wind was on the average, low. There is a general agreement between moth flight and temperature. The absence of moths in plot A on July 3 and July 10 is not due to meteorological factors as moths were flying in plot B on these nights. The absence of moths in both plots

on July 17 is unexplained; the temperature was high, humidity fairly high and wind, moderate. There were fewer moths in flight in the plot during this year than for any previous one and the light trap catch was also very low when compared to later years.

Year 1932. This year was characterized by a moderate temperature with a fairly high humidity. Wind was about average. The major peaks and depressions agree in plots A and C, and both agree with the rise and fall in temperature. On July 4, flight was prohibited by a drop in temperature early in the evening. At –:30 o'clock, the temperature was 63° F., but by the next hour it was 58° F. On July 1, 2, 3, the mean temperature was just below 60° F., but a detailed study of the records shows that the actual temperature on these three nights was below 58° F. by 2:30 Sunset time and hence, prohibited flight.

Year 1933. Temperature in this year was comparatively low. A detailed study of the primary data shows that this year was cold just before and after midnight on many occasions. It was unique in this respect. The humidity was fairly low at first, but soon became higher. Wind was average. The moth flight peaks agree in plots A and C and both follow the temperature curve to a remarkable extent. A temperature rise gives an increase in number of moths in every case except one. Flight was prohibited on July 2, while on July 12 the flight was terminated early because of a drop in temperature.

Year 1934. This year was characterized by high temperatures with comparatively low humidity. Wind was average. The flight of moths to plots A and B were small, while the light trap catch, C, was about average. The three curves agree in two peaks and two major depressions. All show a relationship to temperature, but C is best to follow because of its larger number of moths. The minor variations in this year are not in very close agreement with those of other years. This may be due to the small number of specimens observed. In many cases, there is no apparent reason for lack of flight as flight would occur in one plot and not in another.

Year 1935. The temperature was comparatively high, while the humidity curve is moderately placed as shown both by relative humidity and saturation deficiency curves. The three flight plots, A, B and C, all agree in their major variations and all are in close agreement with the temperature curve except in two cases. The flights in plots A and B, as well as in C, are small and therefore probably give the most inaccurate record of any year, but even here the major flight peaks and depressions follow those of temperature.

Year 1936. This year was characterized by a very high temperature, especially during the middle portion of flight. The humidity was low, the lowest of any year. Wind was fairly high, with high peaks. It was the windiest year observed. Even with the high temperatures, low humidity and high winds of this year, the moth flight curves of plots A and C follow very closely that of temperature.

The Effect of Temperature on Flight during Individual Nights

The effect of temperature upon flight is strikingly shown within an individual night. On certain nights the temperature may be high enough

to allow flight in the early portion of the evening, but falls rapidly and prohibits flight. This effect can readily be seen in the selected nights shown in Table 1.

TABLE 1.—PROHIBITIVE EFFECT OF LOW TEMPERATURE ON FLIGHT, WITHIN INDIVIDUAL NIGHTS, CHATHAM, ONTARIO

Date	Hour	Temp.	Rel. hum.	Evapor- ation	Satur. deficit	Wind	Precipi- tation	No. of moths	
								A	B
July 20, 1927	:30	63	77	—	3.30	83	00	12	
	1:30	57	94	—	0.74	00	00	15	
	2:30	56	91	—	0.99	00	00	0	
July 30, 1928	:30	62	72	.09	3.95	82	00	7	
	1:30	56	89	.02	1.29	36	00	0	
July 10, 1929	:30	64	63	.09	5.66	142	00	1	
	1:30	60	73	.03	3.60	36	00	0	
	2:30	57	85	.00	1.68	36	00	0	
July 21, 1929	:30	65	58	.09	6.67	36	00	1	2
	1:30	61	72	.02	3.80	73	00	2	4
	2:30	59	80	.01	2.35	61	00	0	0
July 7, 1930	:30	64	71	.10	4 44	100	00	1	
	1:30	60	80	.02	2.53	55	00	2	
	2:30	58	83	.04	2.08	62	00	2	
	3:30	56	90	.08	1.14	36	00	0	
July 12, 1933	–:30	70	54	—	8.63	36	00	3	
	:30	62	68	.02	4.55	36	00	5	
	1:30	58	80	.02	2.48	36	00	2	
	2:30	56	85	.02	1.73	36	00	2	
	3:30	54	87	.00	1.44	82	00	0	
	4:30	53	89	.00	1.44	36	00	0	
	5:30	53	90	.00	1.04	36	00	0	

Temperatures from 59° F. to 56° F. not only prohibit flight altogether if they occur early enough in the evening, but prohibit flight whenever they occur in the nightly flight cycle.

If temperature on individual nights has such a great influence on the flight of moths, one must consider what the effect of the general character of the season in regard to temperature would have upon flight. As pointed out above, 1927 and 1928 were comparatively cool years, while 1931, 1934 and 1936, in particular, were warm years. This consideration will be taken up later, after the remaining physical factors have been discussed. It might be mentioned here, however, that it would appear as if the seasonal night temperatures had very little effect in lengthening or curtailing flight, although 1931 and 1935 had the shortest flight seasons and both were warm years.

A Review of the Literature on the Effect of Temperature on Flight

In the literature dealing with the European corn borer, most of the references deal with the effect of temperature upon flight through the association of egg-laying activity. These references will be dealt with later.

Stirrett (13) found that in the early years of the present study, no moths flew when the temperature reached as low as 57° F. Huber (9) gives data showing the numbers of moths caught at definite temperatures, but does not discuss the effect on flight proper except through egg-laying activity. Hervey and Palm (7) found that in New York, in 1933, temperatures between 70° F. and 75° F., were most favourable for flight. At mean temperatures, below 70° F., the moth catch dropped off rather rapidly and below a mean of 60° F., the activity was much retarded. The mean temperature used by them was that of the temperature between 8:00 p.m. and 4:00 a.m.

There is a very close agreement between the findings of Hervey and Palm and our own work as to the optimum and range of temperatures at which the flight of moths takes place.

Among other Lepidoptera, several authors have studied the effect of temperature on flight. According to Uvarov (14) who gives a very good summary of the literature up to 1930 upon Lepidoptera and other insects, most of the authors have found a positive correlation between temperature and flight activities, although Ainslie (1) concluded that the flight of crambid adults was not correlated with temperature. Cook (5) made extensive studies upon the flight of various species of noctuid moths and found temperature had a positive effect upon the number of moths captured, especially was this so when the humidity was low.

Yothers (16) found a definite relationship between codling moth activity and temperature. Most codling moths were captured when the mean daily temperature was above 70° F. A sudden drop in temperature practically prohibited all flight until it warmed again.

Collins and Nixon (4) found the optimum temperature for the flight of *Eucosma ocellana* Schiff. to be between 65° F. and 70° F. They found a positive correlation at other temperature ranges also, and noted that few Lepidoptera fly when the temperature falls below 60° F.

This last observation is very nearly parallel to observations made many times during the present study, that when the temperature is around 60° F. or below, very little insect life of any type and especially of Lepidoptera, was noticed in the field. Such a night was July 2, 1933, when no corn borer adults or insect life of any kind was noticed in flight. The character of the night is shown in Table 2 as measured by hourly observations according to Sunset time.

TABLE 2.—THE PHYSICAL FACTORS, JULY 2, 1933, TO SHOW TYPE OF NIGHT IN WHICH NO INSECTS OF ANY KIND WERE NOTED IN FLIGHT IN CORN FIELDS

Sunset time	Temp.	Rel. hum.	Evap.	Sat. def.	Wind vel.	Precipitation
–:30	64	75	.08	3.84	700	00
:30	61	74	.08	3.55	818	00
1:30	60	71	.09	3.85	732	00
2:30	59	73	.05	3.43	551	00
3:30	58	78	.02	2.72	424	00
4:30	56	78	.04	2.53	616	00
5:30	56	73	.04	3.07	571	00

It would appear from the present work and from the above review of the literature that with very few exceptions flight is directly correlated with temperature and that temperatures below 60° F. have a marked

effect in retarding flight. The optimum temperature for the flight of the borer adult is very close to that for *Eucosma ocellana* Schiff., and other nocturnal Lepidoptera.

(B) Humidity

Humidity was measured as saturation deficiency expressed as a vapour pressure in millimetres of mercury and as relative humidity. Throughout the discussion it is referred to under "saturation deficiency". In Figures 2, 6 and 10, however, relative humidity is also plotted and discussed for the years treated in these figures.

The Optimum Humidity of Flight

The number of moths flying in plots A and B during the last ten years are plotted against humidity as shown by the saturation deficiency in Figure 12. This is done without considering the influence of any other factor. Because of the length of observations the data should give a close approximation to the humidity preferred by the moths for flight. It will be seen from Figure 12 that moths flew mostly during high humidity periods: 38% of the moths flew between a saturation deficiency of 0 and 2 mm.; 89% flew between a saturation deficiency of 0 and 6 mm.

An exploratory histogram was made from the data to see if sexual preferences existed in the flight at various humidities, but none could be found. Both sexes appear to have the same preferences of humidity for flight.

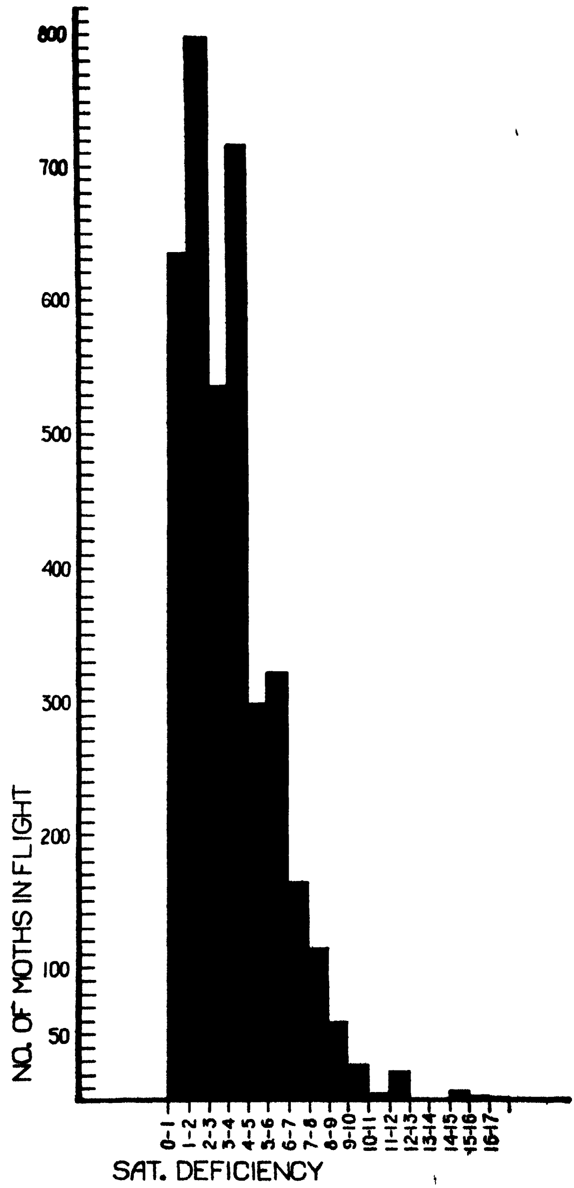

FIGURE 12. Humidity at which flight of moths took place, Plots A and B, Chatham, Ontario, 1927–36.

The Effect of Humidity upon Nightly Flight

From a study of Figures 2 to 11, the character of each flight season and each individual night as regards humidity can be seen and studied.

The year 1927 was one of high humidities at the time of flight as shown by the low saturation deficiency curve and the highly placed relative humidity curve. The curve of flight does not seem to have any relationship to the curves of humidity.

The year 1928 was also a year of high humidity at the time of flight as shown by the low saturation deficiency curve. The average saturation deficiency for any night did not reach 6 mm. The curve does not bear any relation to that of flight.

The year 1929 was not quite as humid during the time of flight as either 1927 or 1928. The curve is higher on the scale. No relationship is shown between moth flight and saturation deficiency.

The year 1930 was much like the year 1929 in its atmospheric moisture relations in the early period of flight, but a very hot, dry period occurred about July 18. Flight terminated abruptly, but whether it was the natural termination of flight or the effect of low humidity or high temperature, or both, is unknown. No correlation exists between flight and saturation deficiency.

The year 1931 was relatively dry during the period of flight. No relationship between moth flight and humidity is indicated for any of the three flight curves.

In the year 1932, humidity was somewhat higher than in 1931 as is shown by the position of the saturation deficiency curve on the chart. No relation is apparent between flight and humidity.

In the year 1933, the humidity was about the same as in the year 1931. These two years are halfway between the years of highest humidity and those of lowest humidity. No relationship is indicated between moth flight and humidity, even when the temperature is relatively high as in the last few days in June.

The years 1934 and 1936 were relatively dry years with the lowest humidities of any of the years studied. They also showed the greatest variations from night to night. In the year 1934, there does not appear to be any correlation between moth flight and humidity, even when the temperature is comparatively high as during the last of June and the first of July.

The year 1935 is an intermediate one as far as humidity is concerned. It was much like the years 1931 and 1933, except that its period of lowest humidity occurred during the middle period of flight. There is an indication, on June 13, that flight might have been lessened because of low humidity during a high temperature period.

The year 1936, and the year 1934, as has been pointed out, were the two driest years encountered during the ten years under study. No relationship between flight and humidity can be seen from the curves of each in Figure 11.

From Figures 2 to 11, and from the summary given above for each year, it will be seen that humidity as encountered during the ten years and

as indicated by saturation deficiency has no influence upon the nightly variations in the flight of moths. This may be due to the fact that any effect humidity might have is masked by the greater response of the moths to changes in temperature.

It should be pointed out that moth flight takes place during the time of the day when humidity is naturally high. Only on a very few occasions did the average saturation deficiency reach 10 mm. during the observations.

The Effect of Humidity upon the Time of Night of Flight

An attempt was made to ascertain whether or not the humidity had an influence upon the time of night at which the moths begin to fly. Saturation deficiencies at similar temperatures were plotted against the time of flight of first moths in the evening and it was found that humidity was not a controlling factor on the time of flight.

The Effect of Humidity on the Flight of Nocturnal Lepidoptera

There is no literature referring to the effect of humidity upon the flight of the European corn borer. According to Uvarob (14), Picard, Necheles and Martini suggested that nocturnal insects are active at night because they require a high degree of humidity. In our own case, the humidity varied greatly at the time of commencement of moth activity and the humidity did not appear to have any influence over flight. Cook (5), in studying the flight of nocturnal Lepidoptera to light trap considered relative humidity the most important factor studied. Any increase in the 7:00 p.m. relative humidity up to 54% tended to increase the catch, while beyond this value it decreased the catch in almost the same proportion. Cook's work is not of great value as he measured humidity in terms of relative humidity at varying temperatures. He did not, therefore, know the exact state of the atmosphere in regard to humidity from night to night.

The effect of variations in humidity during the various seasons upon flight, oviposition and establishment is discussed again later.

(C) Wind

The effect of wind upon the flight of the European corn borer moth has never been adequately studied. Most of the work has been done in connection with the effect of winds in spreading the insect into new territory. This phase is not considered in the present paper. Huber (9) relates that relatively strong winds cause the moths to seek shelter on corn plants or if not flying over corn, on other plants nearby.

The average wind velocity for each night of observation is shown in Figures 2 to 11. Wind was measured in feet per minute. From a study of these figures it can be seen that the years 1927, 1928, 1931 and 1935 had low winds during the flight period, while during the years 1929, 1930, 1932, 1933, and 1934 the wind velocity was higher but variable. The wind obtained its highest velocity during the year 1936. A study of the curves of flight and the curves of wind velocity for any year fail to show a correlation between these two factors.

During the ten years, the wind velocity during flight observations ranged from 0 to 1492 feet per minute or from 0 to 17 miles per hour. Wind of such velocities did not lessen nor prohibit flight.

(D) Atmospheric Pressure

The influence of barometric pressure upon the activities of insects has been summarized by Uvarov (14). This author points out that insects are able to withstand enormous fluctuations in pressure such as can never occur in nature. Pressure in nature, therefore, cannot have a direct fatal effect upon insects.

Cook (5) studied the effect of pressure, temperature and humidity upon the numbers of moths caught in light traps. He concluded that barometric pressure had less influence than either temperature or humidity.

Rhumbler (12), in studying the flight of May-beetles (Melolontha), concluded that they begin to fly in the evening owing to the usual, slight, not over 0.1 mm. rise in barometric pressure which occurs every evening between 9:00 and 10:00 p.m.

In the present study, it was impossible to purchase a barometer until the spring of 1936. Previous to this date, barometric pressure readings were obtained from the Chatham Station of the Meteorological Service of Canada. The pressure was recorded at 8:00 a.m. each day. Exploratory histograms were made for the years 1927-35, inclusive, plotting numbers of moths in flight against barometric pressure, but no correlation was found to exist.

During the year 1936, barometric pressure was taken just before moth flight and at termination of moth flight in the same evening. These data are given in Table 3.

TABLE 3.—BAROMETRIC PRESSURE AT BEGINNING AND END OF DAILY MOTH FLIGHT AND NUMBER OF MOTHS IN FLIGHT, CHATHAM, ONTARIO, 1936.
PRESSURE IN INCHES OF MERCURY

Date	No. of moths in flight	Barometric pressure at beginning of flight	Barometric pressure at end of flight	Type of change in pressure amount		
				Rise	Fall	Amount
June 27	0	29.13	29.13	–	–	0
28	1	29.16	29.24	+		.08
29	0	29.07	–			
30	0	29.20	–			
July 1	2	29.32	29.34	+		.02
2	0	29.24	29.25	+		.01
3	5	29.34	29.32		+	.02
4	0	29.35	–			
5	3	29.48	29.51	+		.03
6	6	29.55	29.54		+	.01
7	10	29.33	29.34	+		.01
8	5	29.27	29.27	–	–	0
9	25	29.29	29.30	+		.01
10	11	29.24	29.26	+		.02
11	18	29.21	29.32	+		.11
12	6	–	–			
13	11	29.27	29.25		+	.02
14	6	29.14	29.27	+		.13
15	4	29.31	29.32	+		.01
16	6	–	29.28	–	–	
17	5	29.24	29.24	–	–	0
18	2	29.18	29.24	+		.06
19	0	29.24	29.28	+		.04
20	0	29.35	29.37	+		.02
21	1	29.35	29.37	+		.02
22	2	29.25	29.24		+	.01
23	1	29.11	–			
24	1	29.25	–			
25	0	29.18	29.23	+		.05

From Table 3 it can be seen that for 1936 there was no correlation between the number of moths in flight and the barometric pressure, either immediately before flight commenced or at the termination of flight. A rising or falling pressure apparently had no influence upon flight.

Under conditions at Chatham, Ontario, the slight rise in barometric pressure observed by Rhumbler, between 9:00 and 10:00 p.m. does not always occur.

(E) Rain Storms

Very few actual records of the effect of rainfall upon the flight of the corn borer exist. Huber (9) concluded from his work in Ohio that hard rains interfere with moth activity, although gentle rains do not necessarily stop flight, providing other conditions are favourable. Stirrett (13) has noted that rain sometimes prohibits moth flight.

The effect of rain storms occurring during the time of flight when all other factors were favourable to flight are synopsized in Table 4. The approximate rate of rain per hour is indicated, but this figure must be used in reference to the factors given under the heading "Remarks".

TABLE 4.—EFFECT OF RAIN ON MOTH FLIGHT— THE INFLUENCE OF RAIN WHEN TEMPERATURE, HUMIDITY, TIME OF OCCURRENCE AND OTHER FACTORS ARE FAVOURABLE TO FLIGHT

Date	Approx. amount of rain per hour, in inches	Effect on flight	Remarks
1927 July 13	.14	Prohibited	Between 8.00 and 10:00 p.m., variable. Moths flew before and after rain.
1927 July 14	02	None	Light drizzle.
1927 July 21	—	None	Electric storm followed by light rain during time of flight.
1927 July 22	.47	Prohibited	Moths flew during light rain period, but did not fly during heavy rain; flew later when it rained lighter.
1928 July 18	.02	None	Light intermittent rain, early portion of flight.
1928 July 21	—	None	Light drizzle for short period.
1928 July 22	1.03	Prohibited	Very heavy rain between observation periods. In light rains immediately after heavy rain, moths flew.
1930 June 30	.06	None	Rain mostly between observational periods.
1931 July 5	—	None	Light rain.
1931 July 21	.22	Prohibited	Moths flew before and after, but not during rain.
1932 July 20	.024	None	Very light rain.
1932 July 21	.17	Prohibited	Severe electrical storm; moths began to fly two hours after storm.
1933 June 24	.05	None	
1933 June 25	.03	None	Much lighter rain during most of period.
1934 July 6	.04	None	Intermittent rain.
1934 July 19	.04	None	Trace of rain previous to 3:30 Sunset time. During this hour, 0.04" rain fell and moths flew.
1936 July 23	.23	Prohibited	Severe electrical storm. Moths flew in light rain during last portion of storm.

Table 4 shows that if other factors are favourable, rain has to be at least at the rate of 0.14 inches per hour to prohibit flight. Moths fly in corn fields during light rains.

(F) Electric State of the Atmosphere

Marchal (11) considered that the vine moths were more active and flew in greater numbers just before a thunder-storm. Uvarov (14) points out that very little is known regarding the effects of thunder-storms upon insect life, but that there is a general impression that insects are more active just before storms. Gourdon (6), as quoted by Uvarov, on the other hand, concludes that the organization of the atmosphere during a thunder-storm causes insects to remain inactive for a long time after the storm owing to stupor produced by ozone.

Three electrical storms occurred in the progress of the observations at time of moth flight during the ten years under study. On July 21, 1927, a severe electrical storm occurred between 7:00 and 8:00 p.m.; no moths were observed before or during the storm. They were not flying before the storm as it was too early in the evening. Moths flew in numbers immediately after the storm and while it was still raining. Temperature was favourable for flight, being 65° F. In this case, the electric state of the atmosphere, due to the storm, did not prohibit flight immediately after the heavy rain was over.

The electrical storm of July 21, 1932, occurred between 7:30 and 8:30 p.m., and moths were not found in flight until two hours later. The temperature was high, the average for the period of observations being 73° F. Moths had been captured in flight at the observation periods under consideration the night before and again the night after the storm. It would appear that the moths were affected by the storm in some manner, but whether it was because of heavy rain or from stupor, as suggested by Gourdon, is not known.

The third interesting storm occurred on July 23, 1936. It took place early in the evening before moth flight had commenced. Moths were in flight immediately after the heavy portion of the storm, and while it was still raining. In this case, the storm did not affect moths in any manner except to prohibit their flight during the short period of heavy rain.

All three storms occurred so early in the evening that their effect upon numbers of moths flying just as they were approaching cannot be measured.

(G) Cloudiness

Records of cloudiness for each hour of the night in relation to flight were secured. In examining these records, it is very evident that the presence or absence of clouds, even at the same temperature, has no influence upon the flight of moths.

(H) Lunar Periodicity

Very little is known regarding the influence of moonlight upon insects. Hora (8) observed that the appearance of swarms of certain Mayflies in India coincided with a definite moon phase. Wheeler and Brown (15)

observed that the periodic swarming of a crustacean at Bermuda coincided with the two weeks of lunar cycle when the moon wanes from the last quarter to the first quarter of the new cycle. Chatanay (3) found that the number of moths caught at light and at baits is greatly influenced by moonlight.

Effect on Annual Cycle of Flight

The question has been raised as to whether or not moths begin to fly when the moon is full and therefore brightest or whether moths appear during the time when there is practically no moonlight. A variation in the time of appearance of moths in the field has been noted as has also a variation in the time of peak of flight. What influence, if any, has the moon upon these variations?

The phases of the moon, as they occurred at Chatham, Ontario, each summer during the flight period have been plotted, together with the moth flight in Figure 13. The solid black triangles represent the moon

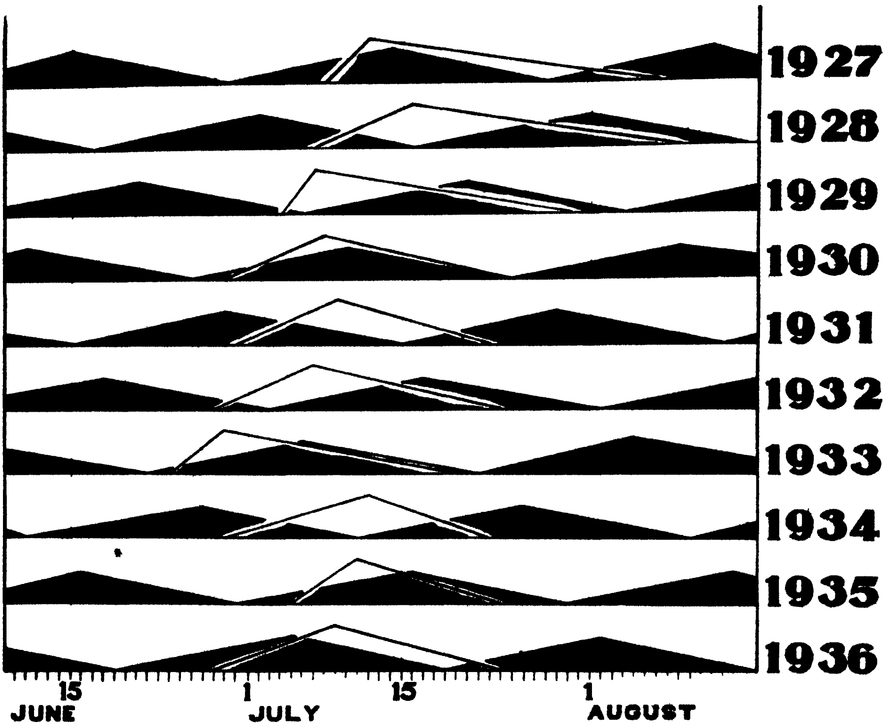

FIGURE 13. Relationship of the moth flight season with moon phases, Chatham, Ontario, 1927–36.

phases. The apex of the triangle is at the date on which the moon was full. The left basal point is at the date on which first quarter phase of the moon occurred and the right basal point is at the date of the last quarter. Beginning at the first quarter, the moon gradually becomes more brilliant until full moon is reached and then gradually wanes until last quarter. The flight of moths is represented by the solid black line. The peak of flight is at the apex of this line.

From Figure 13, it can be seen that the time of moth flight has no relationship to the time of occurrence of the full moon and therefore, no relationship to the intensity of moonlight. In 1927, for instance, moths began to fly during the latter part of the period of increase in moonlight, while in 1928, they began to fly when there was practically no moonlight. This was again the case in 1929. In 1930, moths began to fly during a period of increase in moonlight, but at an earlier date than in 1927. The peaks of flight in 1930, 1935 and 1936 are near the date of greatest amount of moonlight, but vary as to position before and after the peak of moonlight.

Effect within Flight Season

This factor may also be determined from Figure 13. It can be seen that the increase in the number of moths found in the field until finally the peak is reached cannot be correlated with the increase in the amount of moonlight. In 1928, 1931 and 1934, for instance, there was practically no moonlight during the time the moths were at their maximum activity.

The curves of flight in 1927 and 1929 are very similar, but the peak of flight in 1927 occurred just before the curve of maximum amount of moonlight, while in 1929 it occurred at the period of the new moon when there was practically no moonlight.

Effect on Nightly Cycle of Flight

The moon, in all its phases and during any particular phase, is not always visible at Chatham at the time of the day the moths are in flight. A record as to whether or not the moon was up or set and in or out (visible) for each hour of flight for all years was secured. From a detailed study of this record it can be seen that moths fly in numbers without relationship to whether the moon is brightly shining or whether it is not shining, either because it is behind clouds or set.

Table 5 gives selected records which show that moths commence to fly in the evening regardless of whether the moon is visible or not.

TABLE 5.—SELECTED RECORDS SHOWING EFFECT OF MOONLIGHT UPON FLIGHT OF MOTHS

Date	Hour, Sunset time	Temp.	Saturation deficiency	Wind	Full moon	No. moths in flight
July 9	–:30	89	15.75	395	Set	0
	:30	82	9.78	147	Set	0
	1:30	79	7.21	333	Set	10
	2:30	78	6 39	296	Up and out	5
	3:30	76	5.97	777	Up and out	4
	4:30	75	4.28	376	Up and out	6
	5:30	74	3.06	231	Up and out	1
July 10	–:30	87	14.18	149	Set	0
	:30	82	8.63	28	Set	0
	1:30	81	8 11	107	Set	7
	2:30	78	5.15	27	Set	0
	3:30	78	5.15	57	Up, in and out	4
	4:30	75	2.88	32	Up, in and out	0
July 13	–:30	81	9 67	89	Set	0
	:30	80	6.24	99	Set	0
	1:30	79	7.21	23	Set	10
	2:30	79	7.21	24	Set	1
	3:30	76	8.03	89	Set	0

(I) Fog or Mist

Very little is known regarding the effect of mist upon the flight activities of insects. Uvarov (14) sums the present knowledge in a short paragraph. It would appear that mist reacts unfavourably to the flight of moths because it occurs generally upon cold nights when the temperature is too low for flight. Uvarov cites Rothke, however, as authority for the statement that certain insects, which are active at low temperatures, fly during misty nights.

Mist was encountered three times during the ten years' study upon flight. In 1927, there was a fairly thick fog on July 14, accompanied by a drizzle of rain. The temperature was 69° F., with a saturation deficiency of 0.51 and a wind speed of 25 feet per minute. Moths flew abundantly through rain and mist. In 1932, a fairly heavy mist was encountered in the early morning of July 21, while records were still being taken, but no moths had been seen after midnight. The mist occurred when moths were not in flight. The only other mist encountered was on the night of July 13, 1934. The temperature was 67° F., saturation deficiency 0.51, with no wind. Moths flew during the time mist was present.

Mists are rarely encountered during the flight season, but when they do occur and the temperature is favourable for flight, moths continue to fly during mists.

(J) Dew and Guttation

Free moisture, upon plants at night, whether derived as dew from the water vapour in the atmosphere or from the plant itself by guttation, and its relationship to insect activity has never been studied.

Records of the amount of dew present upon the corn plants were secured intermittently during the years 1927, 1932 and 1933, and complete records were taken during the years 1934, 1935 and 1936. Records of the amount of guttation were secured for the years 1935 and 1936.

It was found quite easy to identify water from dew and from guttation in the early part of the evening, but when dew becomes moderate or heavy it is not possible to distinguish the source of the water. Dew appears upon the upper surfaces of leaves and covers the surface of the plants within the field as well as other objects near the corn field, while water from guttation appears along the edges of the leaves and gathers at tip of leaf, and it is not present away from the plant. Water from guttation appears on the plants earlier in the evening than does water from dew. This can be seen from the accompanying record of July 15, 1935. Dew on

Sunset time	*Dew*	*Guttation*
— :30	None	Light
:30	None	Moderate
1:30	None	Very heavy
2:30	Moderate	Very heavy
3:30	Heavy	Very heavy
4:30	Heavy	Very heavy

this night did not appear until 2:30 Sunset time or approximately 10:30 p.m., Eastern Standard time, while water from guttation appeared as early as — :30 Sunset time or approximately 7:30 Eastern Standard time.

The amount of dew varies from year to year and from night to night within the year. In 1927 and 1928, dew was particularly heavy during flight observations, and operators were saturated with water while walking through the corn fields. In 1934 and 1935, there were a considerable number of nights without dew but on others it was quite heavy. The only year in which dew was absent from the fields was 1936. In this year dew occurred only upon three nights during the flight period. Guttation, on the other hand, produced considerable water on the plants during 1936 and in spite of the lack of dew the leaves were moist nearly every night. On a few nights with high temperatures (72° to 78° F.) neither dew nor water from guttation were present in 1936.

The Relationship of Dew and Guttation to Corn Borer Activity

It has been the general impression that adults and young larvae of the corn borer need and utilize free water, and that such is necessary for their well-being. Caffrey (2), for instance, records that moths sip pure water and live as long upon water as upon sugar syrup. Jablonowsky (10) observed moths in flight over clover fields and explained they were drinking dew from leaves and flowers. Dew and guttation have also been mentioned in a general way as a factor influencing larval establishment, although Huber (9) records that young larvae can apparently crawl through bubbles of water and water in the axils of corn leaves without harm.

From the observations upon the flight of moths, it is apparent that dew and guttation have no effect upon the numbers of moths in flight. This is what one would expect.

Dew frequently does not appear or does not become abundant until late in the nightly cycle of flight when the moths are terminating their flight.

In regard to the utilization of water from corn leaves for drinking by adults, it may be stated that no adults have ever been observed drinking in the corn field, but this does not prove or disprove that they do not do so. Adults are generally observed resting upon the central portion of the under side of leaves or upon the perpendicular culms where water from dew and guttation are not present.

(To be continued.)

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BOOK REVIEW

ARGLES, G. K.—A review of the literature on stock-scion incompatibility in fruit trees, with particular reference to pome and stone fruits. (Foreword by Prof. V. H. Blackman, Sc.D., F.R.S.). Technical Communication 9 of the Imperial Bureau of Fruit Production, East Malling, Kent, England, 1937, pp. 113, bibl. 194, 5/- .

The problem of incompatibility has loomed ever larger with the increasing realization of the advantages to be gained by the use of tested clonal rootstocks for the production of uniformly excellent fruit.

The literature on the subject is considerable, but it is scattered over very many journals, bulletins and books, and is not always easy to follow. In it the term "incompatibility" is used extremely loosely and may mean much or little. The author here briefly summarizes the phenomena which occur as the result of slight or pronounced incompatibility in different stock-scion combinations.

The horticulturist is often faced with the problem of growing varieties of fruit in localities where there is no experience to guide him. If he knows that under certain conditions, which may in some respects resemble his own, certain rootstocks have given promising results with particular varieties, at least he has something on which to base his trials. He would be most unfortunate if, as regards the common deciduous tree fruits of commerce, he did not find some guidance in these pages.

The physiologist, moreover, has in this common feature of practical horticultural practice a unique investigational field at his disposal. The author gives him a firm basis on which to work.

First the manifestations or symptoms of incompatibility in fruit trees are considered and their possible causes discussed. Next the compatibility or incompatibility shewn by individual varieties of common deciduous fruit trees in respect of particular rootstocks is noted, considerable attention being paid to the practical field experience of research workers in different parts of the world with particular scions and rootstocks.

Certain general conclusions are drawn with regard to both the symptoms and the cause of inherent incompatibility, and tentative suggestions are made for drawing up a research programme to investigate the problem.

In an appendix covering 40 pages are tabulated the many and often contradictory records of compatibility and incompatibility between particular rootstocks and particular varieties. They should prove helpful not only to the physiological investigator but also to the practical horticulturist.

REPORT OF FOURTH INTERNATIONAL GRASSLAND CONGRESS

The Fourth International Grassland Congress was held in Aberystwyth, Wales, from July 8 to July 23, 1937, under the presidency of Professor R. G. Stapledon.

The report of proceedings has just been issued. It consists of one Volume of 486 pages, which is available from Aberystwyth for two pounds sterling, post free. The report contains a list of the various organizing committees and a complete list of both the participating and non-participating members by country of origin. All the papers presented at the Congress are given in full in either English or German with a short German summary for the English papers and vice-versa.

The proceedings open with an inspiring address from the President wherein stress is given to the great importance of developing our grasslands to the fullest possible extent. The main group of papers are divided into two main sections, plenary and sectional. The former include those of a more general nature and were given before the Congress as a whole. They cover such aspects as grass-drying, pasture types, breeding, the ecotype concept and the value of pastures in erosion control.

The sectional papers fall into six natural divisions as follows:

1. Grassland Ecology, Including Range Management.

   This section provides a number of valuable papers on the ecology of pastures in different parts of the world and records progress in methods of renovation under range conditions.

2. Seeds Mixtures:

   The influence of legumes in mixtures, the formulation of mixtures for specific purposes and management to control the ultimate outcome of a mixture are dealt with.

3. Plant Breeding, Genetics and Seed Production:

   In this section the papers deal with the genetics of red clover, the breeding of grasses, and grassland seed production and pests.

4. Manures and Fertilizers, Soil Aspects of Grassland:

   The influence of lime, nitrogen, phosphorus and potash are all dealt with in this division with greatest emphasis on nitrogen. Only one paper is found on soils. The effect of the various fertilizers on sward composition is given consideration.

5. Nutritive Value of Pastures: Fodder Conservation:

   Artificial grass drying and grass silage are outstanding in the contributions under this heading. Several papers stress the nutritional aspects of ordinary pastures and forage crops.

6. Pastures, Management, Yields and Economics:

Management problems and results are the most prominent in this section but it includes as well detailed results on the effect of varying treatments on single species and methods of determining botanical composition.

The publication as a whole has been carefully edited and furnishes a valuable treatise on many aspects of grassland. Many of the foremost pasture workers of the world have contributed. It should be found in the library of any one directly interested in the pasture problem.

—L. C. RAYMOND.

SCIENTIFIC AGRICULTURE

Vol. XVIII JUNE, 1938 No. 10

VARIETAL SUSCEPTIBILITY OF TOBACCO TO BROWN ROOT ROT IN CANADA[1]

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[Received for publication February 23, 1938]

INTRODUCTION

As far as can be ascertained from a survey of the literature up to the present time, no concerted attempt appears to have been made to establish the existence or non-existence of varietal differences in susceptibility of tobacco to brown root rot. In the earliest report of brown root rot Johnson (1) states incidentally that "there seems to be no difference in varietal resistance to brown root rot." In a later publication Johnson, Slagg and Murwin (2) in Wisconsin point out "that no appreciable variation in resistance to brown root rot occurs in varieties of tobacco *Nicotiana tabacum.*" More recently, Valleau and Johnson (3, 4) observed that "certain varieties show slightly greater resistance, as indicated by less wilting than others . . . . . . at present the development of resistant strains does not seem to offer promise as a means of control."

Field investigations were begun in 1935 on a disease serious in southwestern Ontario and symptomatologically similar to the brown root rot prevalent in certain tobacco-growing areas of the United States. During 1936 in a plot designed originally to compare the morphological characters of 16 flue-cured varieties it was observed, incidentally, soon after the plants were transplanted that brown root rot was present throughout the plot and that consistent differences in varietal reaction to the disease were manifesting themselves. In consequence, a concerted effort was made to follow and compare the development of the disease in this plot, and in the following year experiments were designed to test the varietal susceptibility of both flue-cured and burley varieties. The results obtained to date are reported in this preliminary paper.

METHODS AND MATERIALS

Early in the investigation of brown root rot it was realized that the difficulty in obtaining satisfactory results from field experiments was simply that of inducing the disease at will. Soon, however, it was found

[1] Contribution No. 543 from the Division of Botany, Science Service, in co-operation with the Tobacco Division, Experimental Farms Service, Department of Agriculture, Ottawa, Canada. This contribution forms a part of a co-operative investigation on brown root rot of tobacco between the Dominion Laboratory of Plant Pathology, St. Chatarines, Ontario, and the Dominion Experimental Station, Harrow, Ontario.
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that on selected areas of the lighter tobacco soils at the Harrow Experimental Station brown root rot could, with reasonable certainty, be expected to develop in the tobacco crop, provided one or more satisfactory crops of corn preceded the tobacco. It was on such plots of ground that the relative resistance of flue-cured varieties was compared in 1936, and of both flue-cured and burley varieties in 1937. For these experiments, all varieties were planted on the same day and care was taken to subject all varieties and plants to similar conditions from the date on which seed was sown until they were transplanted to the field. Notes as well as photographs were taken of the different plots at intervals throughout the growing season. Frequent root examinations were also made to determine the relative severity of the disease on different varieties and also to find out whether or not affected plants were also suffering from black root rot or other root troubles. In so far as possible plot values were estimated and assigned throughout the season and yields were taken when the crop matured. It was considered unnecessary to include all such information in the present paper, and except for the experiment involving burley varieties in 1937 only the relative resistance of the different varieties estimated from the above information has been enumerated. Additional information was also obtained by careful observations of the occurrence of brown root rot, not only in all tobacco plots on the Station but also in all fields where the disease was encountered during an annual tobacco disease survey.

RESULTS

Flue-cured Varieties, 1936

In 1936, eight varieties of flue-cured tobacco were grown in randomized ($\frac{1}{32}$ acre) plots on 4 ranges, replicated 4 times, and 8 others in single 2-row plots. Fertilizer and cultural treatments were identical on all plots and, as mentioned previously, corn had preceded tobacco in the rotation. Definite differences in the size of above-ground parts of the different varieties were apparent 3 weeks after transplanting. Examination of the root systems of plants of different varieties showed that the amount of discoloration and rotting of the root systems was usually directly proportional to the degree of stunting of the above-ground parts.

A list of the varieties with their plot values, estimated yields per acre, grade indexes and reaction to brown root rot has been summarized in Table 1. As will be observed from an examination of this table, wide differences in results were obtained for different varieties (Plate I). Throughout the list, correlation between plot values, yields, and reactions will be observed. The marked degree of resistance of the varieties Bonanza, White Mammoth, Duquesne, and White Stem Orinoco was both outstanding and consistent throughout practically all ranges and replications. The same was true for certain of the varieties listed as susceptible, particularly Yellow Mammoth and White Stem Willow Leaf. Certain other varieties, however, were not entirely consistent in their reaction, parts of rows being severely stunted while other parts appeared to make normal growth. In such cases, however, the variety was regarded as susceptible, its behaviour explainable on the premises that the disease was not uniformly present throughout the soil of the entire area. Mention should also be made of the apparent measure of correlation between grade index and

reaction. Though this correlation was not marked, nevertheless, those varieties which exhibited greatest resistance to brown root rot also possessed highest grade indexes.

TABLE 1.—SUMMARY OF RESULTS OF AN EXPERIMENT IN VARIETAL SUSCEPTIBILITY OF FLUE-CURED TOBACCO VARIETIES TO BROWN ROOT-ROT IN 1936

Variety	Plot value July 25	Yield per acre in lbs.†	Grade index	Reaction
			cts.	
Adcock	40.0	88	27.2	Highly susceptible
Bonanza	73.5	447	30 1	Resistant
Cash	40.0	103	21.7	Susceptible
Duquesne	87 5	427	26 6	Resistant
Gold Dollar (strain 70B)	30 0	0	0.0	Highly susceptible
Gold Dollar (strain 70A)	70 5	422	23.6	Resistant
Gold Leaf	40.0	223	17.9	Susceptible
Harrison's Special*	65.0	388	25.9	Resistant
Jamaica Wrapper	40 0	94	26.4	Highly susceptible
Lizzard Tail	40 0	210	22.2	Susceptible
Silk Leaf	50.0	119	17.2	Susceptible
White Mammoth	77.5	420	25.7	Resistant
White Stem Willow Leaf	28 5	55	2 .7	Highly susceptible
White Stem Orinoco	70 0	449	22.9	Resistant
Warne	60.0	179	21.2	Susceptible
Yellow Mammoth	28.5	56	17.9	Highly susceptible
Yellow Bud Pryor	45.0	71	21.7	Highly susceptible

* The identity of this strain of Harrison's Special has not yet been definitely established.
† From two primings; then destroyed by hail.

Flue-cured Varieties, 1937

The experiment designed for the purpose of testing the resistance of flue-cured varieties in 1937 proved for the most part unsatisfactory due principally to the mild form of the disease on the ground selected. However, from experimental plots designed for other purposes but planted with flue-cured varieties and having a crop history appropriate for the development of brown root rot, certain interesting information was obtained. Where the disease was more or less uniformly distributed in these plots and where different varieties were grown adjacently, Yellow Mammoth and White Stem Willow Leaf were consistently more seriously affected by brown root rot than White Mammoth, Bonanza, Duquesne, and White Stem Orinoco.

Burley Varieties, 1936

In 1936 no experiment was specifically designed to determine the relative resistance of burley varieties. However, careful examinations of plots of adjacent but different varieties on soil where brown root rot developed in severe form yielded the evidence that the varieties Harrow Velvet and Halley's Special were consistently more severely affected than Judy's Pride and Kelley.

Burley Varieties, 1937

In 1937 two plots of ground, which had during 1936 produced excellent crops of corn and which were regarded as being especially favourable for the development of brown root rot, were selected for testing the relative

resistance of the common burley varieties. On each plot, duplicate rows of seven varieties were grown with the exception of the variety Kelley (306), which was replicated twice on each plot. Throughout one of these plots brown root rot appeared to be more or less uniformly distributed in severe form, and consistent differences in the relative resistance of the varieties became evident. A summary of the results of this experiment on the severely-affected plot appears in Table 2 (see Plate II). Results obtained from the second plot are not given because on it the disease did not occur in epidemic form. To supplement the tabulated information, a graphic representation of all varieties and plants in this plot, their relative positions and the degree of infection is presented in Figure 1. The severity of

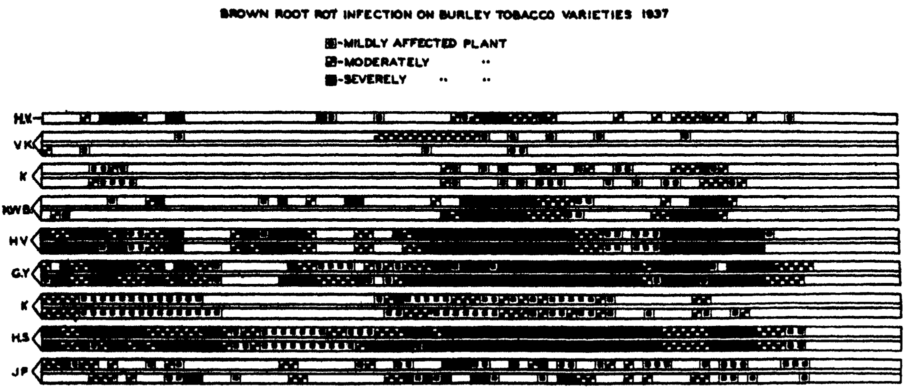


FIGURE 1. H.V.—Harrow Velvet (2 rows and 1 guard row). V.K.—Vimont Kelley (2 rows). K.—Kelley (4 rows). K W.B.—Kentucky White Burley (2 rows). G.Y.—Gays Yellow (2 rows). H.S.—Halley's Special (2 rows). J.P.—Judy's Pride (2 rows).

infection of individual plants was arbitrarily estimated from the size of the above-ground parts. After considerable investigation of this point on the plot in question it was determined that for the most part the size of the plant above-ground varied directly with the infection of its root system.

TABLE 2.—A SUMMARY OF THE RESULTS OF AN EXPERIMENT TO DETERMINE THE REACTION OF BURLEY TOBACCO VARIETIES TO BROWN ROOT ROT IN 1937

Variety	Relative infection and no. of plants				Total no. infected plants	Yield per acre in lbs.	Reaction
	Healthy	Mild	Moderate	Severe			
Vimont Kelley	162	10	12	0	22	948	Resistant
Kelley 306 (average 4 rows)	119	43	21	1	65	656	Resistant
Kentucky White Burley	130	7	18	29	54	689	Moderately resistant
Judy's Pride	111	32	26	15	73	527	Moderately resistant
Harrow Velvet	56	17	26	85	128	441	Highly susceptible
Gays Yellow	41	16	38	89	143	356	Highly susceptible
Halley's Special	24	29	41	90	159	300	Highly susceptible

An examination of Table 2 reveals wide variations in the yield of different varieties. It will be observed that there is a definite and consistent correlation between the number of healthy plants in the different varieties and their respective yields, the number decreasing with the yield. A similar correlation is apparent between the total number of infected plants in each variety and the yield, the number in this case increasing as the yield decreases. It should be mentioned that both the yield figures and grade index for the variety Judy's Pride were somewhat lower than they should normally have been, due to barn burn during curing operations.

Another important fact in connection with the figures presented in Table 1 is the relative severity of the disease in the different varieties. In varieties such as Kelley, Vimont Kelley, and Judy's Pride which appear to offer a measure of resistance to brown root rot the values in the "moderate" and "severe" columns of Table 2 decline sharply. This is in direct contrast with the trend in the highly susceptible varieties such as Harrow Velvet, Gays Yellow, and Halley's Special. The reaction of Kentucky White Burley, mentioned again below in connection with Figure 1 was difficult to determine, as will be observed by an examination of the figures, but this variety appeared to offer some measure of resistance.

The facts presented in Table 2 strongly indicate that brown root rot, rather than other factors such as inherent varietal differences, was primarily responsible for the differences demonstrated by this experiment. Aside from these facts, however, it is quite possible that the reaction of these varieties to brown root rot in the future may not always be precisely as they are listed in Table 2.

Before continuing with a discussion of Figure 1 it should be mentioned that confirmation of the relative resistance of the varieties Kelley and Judy's Pride as contrasted with the extreme susceptibility of Harrow Velvet and Halley's Special was obtained in 1937 on a "brown root rot" plot widely separated from the one just discussed, the resistance of these varieties being tested in single adjacent rows (Plate II, lower).

An examination of Figure 1 elucidates certain facts not presented in the table. Before discussing these it should be pointed out that one outside row of Harrow Velvet plants, adjacent to Vimont Kelley, has been represented in the chart. Though this row of plants was used in the experiment only as a guard row and, therefore, not utilized in the results, it was, nevertheless, included in the chart to show the presence of the disease in the soil to the outside of the plot, the infection of the susceptible variety Harrow Velvet contrasting rather sharply with that of adjacent varieties. Though the disease was apparently more concentrated in severe form in one portion of the plot and entirely lacking in one end, nevertheless, consistent differences in the incidence of infection on different varieties is apparent. Susceptibility of the variety Harrow Velvet is apparent not only by the large number of severely affected plants in the two rows at the centre of the plot, but also by the number of affected plants in the guard row. Vimont Kelley appeared to exhibit a measure of resistance though this is not convincingly demonstrated because of its location in the more mildly diseased portion of the plot. Virtually the same may be said for Kentucky White Burley though the chart indicates a lesser degree of resistance for this variety. On the other hand resistance on the part of

the variety Kelley appears to be much more convincingly demonstrated because in none of the four rows of this variety did the disease manifest itself in severe form. The mild infection of the plants of this variety contrasts sharply with the severe infection in the highly susceptible varieties Gays Yellow and Halley's Special on either side. The variety Judy's Pride also appears to offer a distinct measure of resistance when its reaction is compared with that of the adjacent variety, Halley's Special, in the more severely diseased portion of the plot.

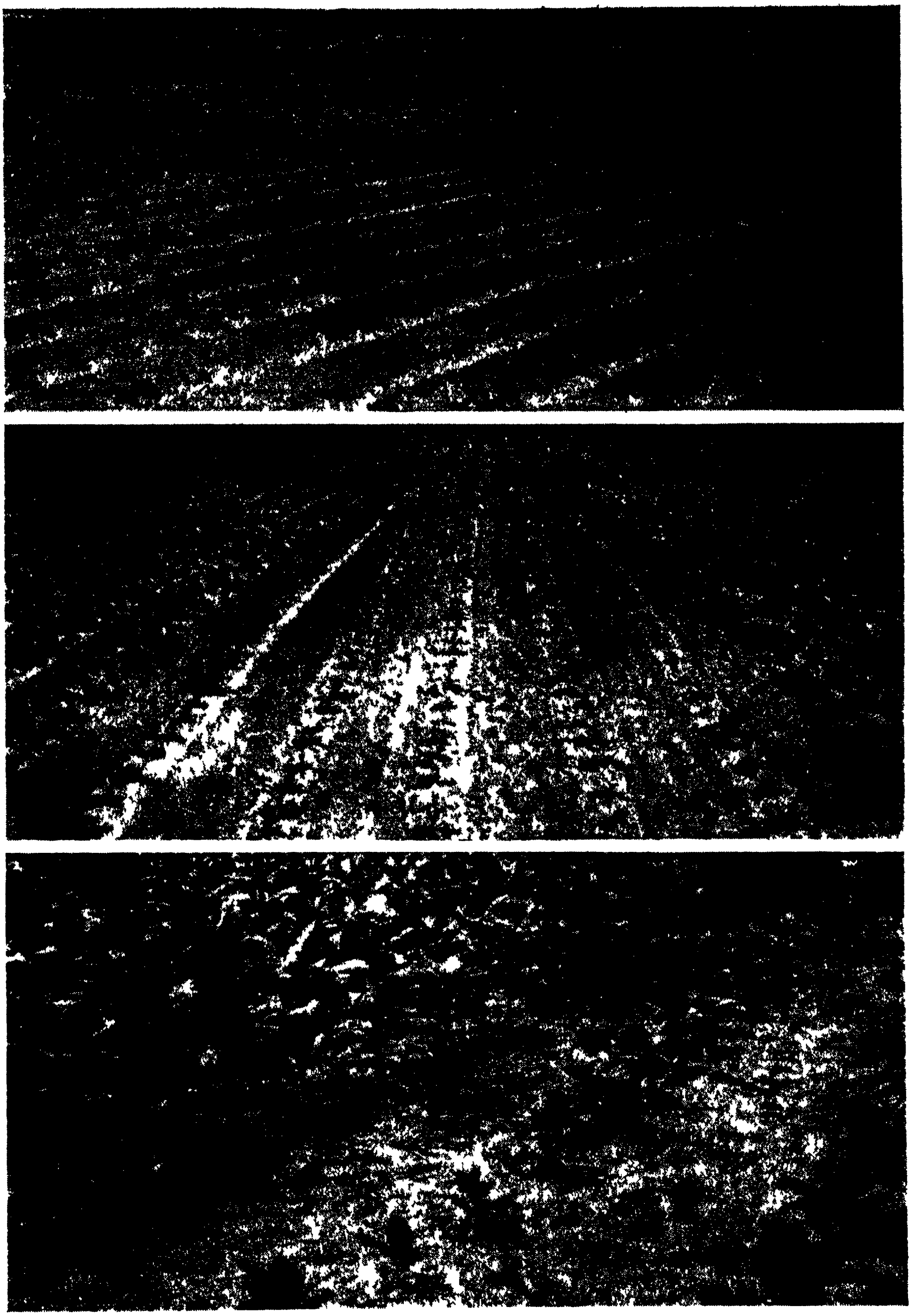
DISCUSSION

From the practical standpoint the demonstration of differences in varietal susceptibility of tobacco to brown root rot is of considerable value, offering, as it does, interesting possibilities for control. The extreme susceptibility of the flue-cured varieties Yellow Mammoth and White Stem Willow Leaf has contrasted strikingly with the apparent resistance of the varieties White Mammoth, Bonanza, Duquesne, and White Stem Orinoco. In the burley varieties, the extreme susceptibility of Harrow Velvet, Halley's Special, and Gays Yellow as compared with the measure of resistance offered by Kelley and Judy's Pride has also been outstanding. However, although the differences in varietal susceptibility just mentioned, as well as certain others pointed out previously, have been both marked and in general quite consistent during the past two years, nevertheless, there is no positive assurance that they will remain so.

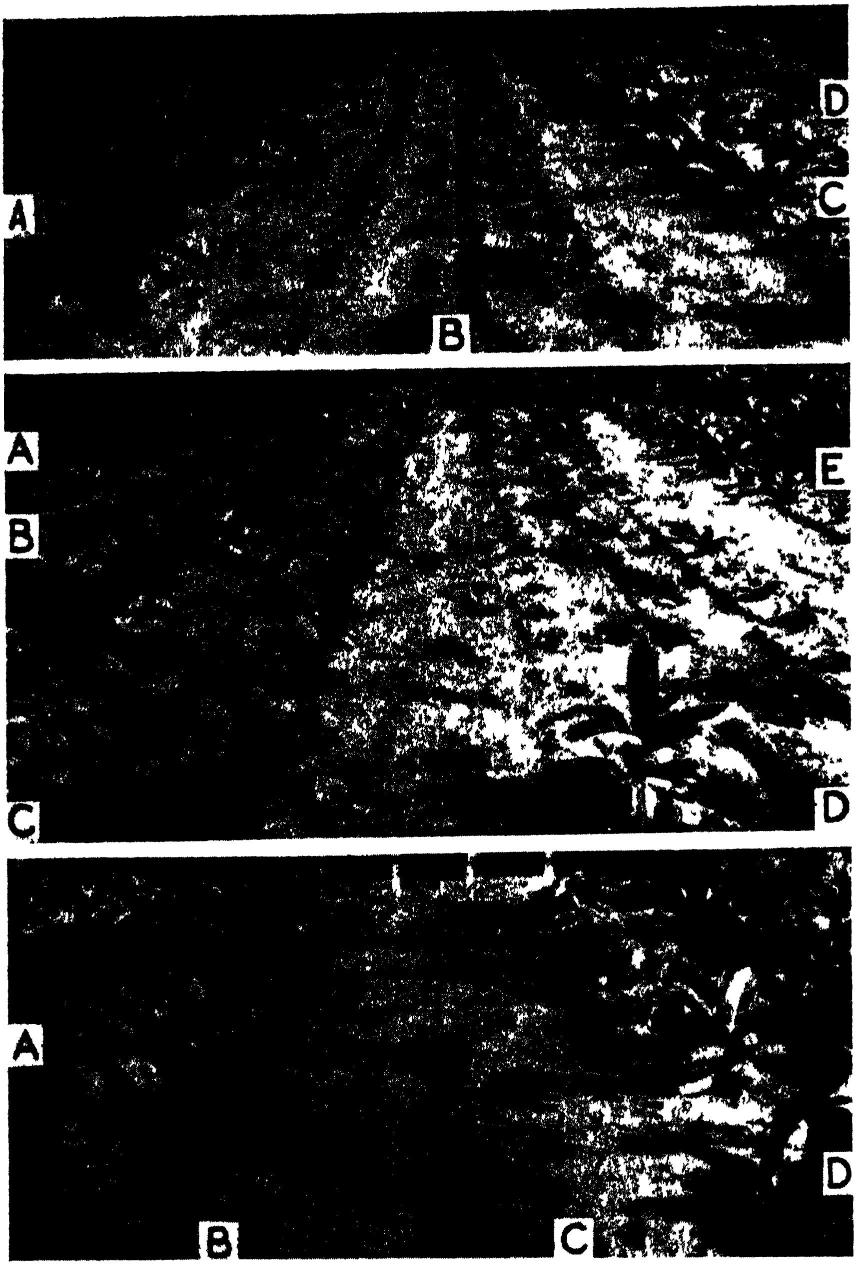
In field experiments involving varietal susceptibility there is always the possibility of interpreting escape as resistance. This danger is reduced to a minimum, however, when results are obtained from replications and from widely-separated plots, as was usually the case in the present experiments. In the present instance there is also the possibility that the root disease under investigation in Canada may be different from the disease known as brown root rot in the United States. However, both symptoms and the circumstances under which this tobacco disease develops strongly indicate it to be similar to the brown root rot reported from and still existent in the Connecticut Valley.

It should be emphasized in the present investigation that resistance to brown root rot of the flue-cured and burley varieties referred to above is in no instance regarded as absolute but rather as relative. In the field, for instance, cases have been observed of Bonanza (flue-cured) and Judy's Pride (burley) varieties affected to some extent with brown root-rot. In the majority of such cases, however, it was impossible to compare their reaction with that of other varieties since only one variety was planted in a single "root rot" field.

Another interesting but puzzling fact disclosed by the investigation to date has been the observation that the burley variety Harrow Velvet which is outstandingly resistant to black root rot, appears to be one of the most susceptible varieties to brown root rot. On the other hand, the varieties Judy's Pride and Kelley, which are extremely susceptible to black root rot, appear to be markedly resistant to brown root rot. In conclusion, it may be pointed out that while the results of this investigation to date must be regarded as preliminary, they have demonstrated a promising possible means of control for brown root rot in Canada and amply warrant further investigation along these lines.



Varietal resistance of flue cured varieties of tobacco to brown root rot *Upper* First range (lower) to right (short plants) Yellow Mammoth, to left—(taller plants) White Mammoth Note plot differences on all ranges *Middle* (Five rows for variety) First range—(right) Bonanza (centre) Yellow Mammoth, (left) Duquesne Second range—(centre) Duquesne *Lower* (right) Yellow Mammoth, (left) Bonanza (after first priming).



Varietal resistance of burley varieties of tobacco to brown root rot. *Upper:* (Duplicate rows) A—Judy's Pride, B—Halley's Special, C—Kelley, and D—Gay's Yellow. *Middle:* (Duplicate rows) A—Judy's Pride, B—Halley's Special, C—Kelley, D—Gay's Yellow, and E—Harrow Velvet. *Lower:* (Single rows) A—Kelley, B—Halley's Special, C—Harrow Velvet, D—Judy's Pride.

SUMMARY

(1) Differences in varietal susceptibility of flue-cured and burley tobacco varieties to brown root rot in Canada are reported for the first time.

(2) Two-years' experiments have indicated extreme susceptibility to brown root rot in the flue-cured varieties Yellow Mammoth, White Stem Willow Leaf, and considerable resistance in the varieties White Mammoth, Bonanza, White Stem Orinoco and Duquesne. Of the burley varieties, Harrow Velvet, Gays Yellow and Halley's Special proved highly susceptible while Judy's Pride and Kelley offered distinct resistance.

(3) Certain burley varieties which are most susceptible to black root rot appear to be most resistant to brown root rot in Canada, and *vice versa*.

ACKNOWLEDGMENT

Thanks are gratefully extended to Dr. G. H. Berkeley, in charge of the Dominion Laboratory of Plant Pathology, St. Catharines, and to Mr. H. F. Murwin, in charge of the Dominion Experimental Station, Harrow, for suggestions offered during the course of the investigation.

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

IV. THE OVIPOSITION AND ESTABLISHMENT PERIODS. ANNUAL CYCLE OF OVIPOSITION. DAILY CYCLE OF OVIPOSITION. FLIGHT AND OVIPOSITION. EGG MORTALITY AND SURVIVAL. LARVAL MORTALITY AND SURVIVAL.

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[Received for publication January 12, 1938]

THE OVIPOSITION AND ESTABLISHMENT PERIODS

Review of the General Literature

The literature dealing with oviposition and establishment is scattered in general references to the life history and control of the borer. The largest portion of the literature deals with variations in oviposition and establishment in relation to corn types and varieties, or with corn planted at various dates. We are not concerned with these subjects in the present paper and will not review the literature referring to them.

Schmidt, in 1835, was the first to refer to the eggs and young larvae according to Jablonowski (11). Schmidt discovered that the eggs were laid on the leaves and stalks of millet in Hungary.

Taschenberg, in 1880, was apparently the first to describe eggs on corn; he found eggs on the sheaths of leaves. He knew also that the larvae, upon hatching, burrowed into the stalk.

Bako, of the Hungarian Entomological Station, published a general paper on the corn borer according to Jablonowski (11) in which he described the eggs as being laid upon corn leaves in little clusters containing a minimum of from 22 to 35 eggs.

Vinal (20) was the first American worker to describe the eggs. This author, in 1917, stated that they were laid on the corn stalks, an impression he no doubt obtained from the scanty European literature. Vinal and Caffrey (21) two years later, pointed out that the eggs were laid in masses of from 5 to 50 eggs upon the under surface of corn leaves.

OVIPOSITION

The Annual Cycle of Oviposition

Detailed records of egg laying by days and by individual corn plants have been secured for each year. In 1929, due to a misunderstanding, egg laying had commenced before our records were started and part of the data was missed. In 1930 and for a portion of 1931, in 1935, and in a portion of 1936, egg laying records were taken every other day instead of every day as in the other years.

[1] Entomologist in Charge.

The Seasonal Limits and Fluctuations in the Oviposition Period

The seasonal limits and seasonal fluctuations are shown in Figures 1 and 2 and in Table 1.

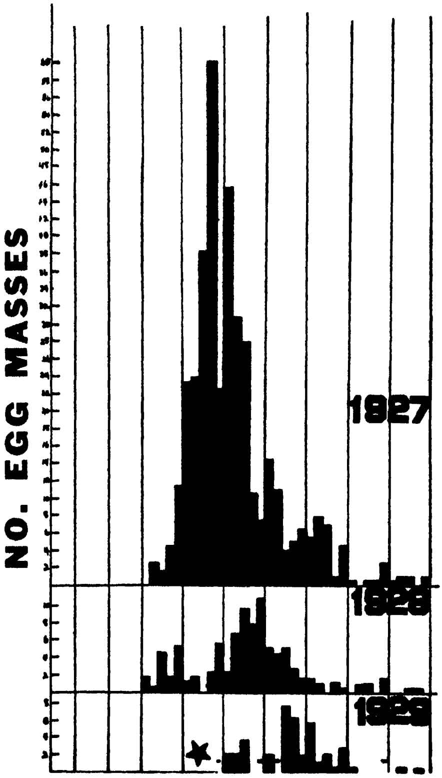

FIGURE 1. Number of egg masses laid daily on 100 corn plants, Chatham, Ontario, 1927–29. The dashes indicate nights upon which records were not secured; eggs laid on these nights are included with those of the next night. The star indicates that early records were not secured in this year.

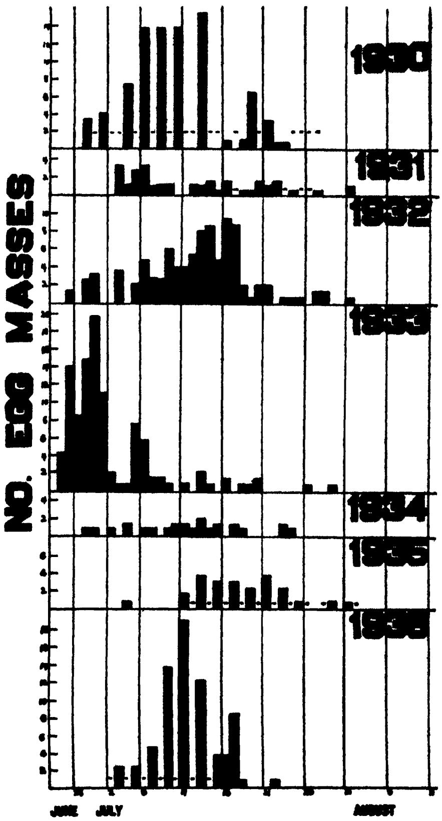

FIGURE 2. Number of egg masses laid daily on 100 corn plants, Chatham, Ontario, 1930–36. The dashes indicate nights upon which records were not secured; eggs laid on these nights are included with those of the next night.

TABLE 1.—THE SEASONAL LIMITS OF THE OVIPOSITION PERIOD, CHATHAM, ONTARIO, 1927–36

Year	Date of commencement of oviposition	Date of apparent peak of oviposition	Date of termination of oviposition
1927	July 7	July 14	August 9
1928	July 6	July 20	July 30
1929	July 4	—	August 8
1930	June 29	July 13	July 24
1931	July 3	July 6	July 31
1932	June 27	July 16	July 31
1933	June 26	June 30	July 20
1934	June 29	July 13	July 24
1935	July 4	July 13	July 31
1936	July 3	July 11	July 22
Average date	July 2	July 15	July 29

Crawford and Spencer (5) found eggs as early as June 21 in Elgin county, Ontario, in 1921, but egg laying did not become general until about July 1. Ficht (unpublished) found eggs at Wheatley, Ontario, on June 23, 1925 and at Chatham, Ontario, on July 5, 1926. Bottger and Kent (2) have studied the seasonal oviposition periods in southern Michigan. Their data are reproduced in Part II, Table 2, page 465. Egg laying in Ontario occurs a few days later than it does in southern Michigan.

TABLE 2.—RATE AT WHICH OVIPOSITION PEAK IS REACHED AFTER COMMENCEMENT OF FLIGHT, CHATHAM, ONTARIO, 1927–36

Year	No. of days to reach peak	Year	No. of days to reach peak
1927	7	1932	19
1928	14	1933	4
1929	9	1934	14
1930	14	1935	9
1931	3	1936	8
Average for all years			10

The Rate of Developing Oviposition Peak

There is a considerable variation in the rate at which the oviposition peak is reached from year to year. This is shown in Table 2.

A detailed knowledge of the character of the annual cycle of oviposition and its variations is important when considering experimental or practical control by ovicides or larvicides, as very often the time of application will govern the success or failure of the operation.

The Magnitude of Oviposition

Magnitude of oviposition can be measured in a number of ways. It can be measured according to the number of egg masses per 100 plants, or by the total number of eggs laid per 100 plants. Both of these measurements will be considered below.

The Seasonal Magnitude of Oviposition

The magnitude of oviposition, based upon the number of egg masses laid per 100 plants is shown in Figures 1 and 2. There is a considerable variation from season to season. The largest number of egg masses for any one season was laid in 1927, while the least number was laid in the years 1931, 1934 and 1935.

The Number of Eggs per Mass

The number of eggs found in each mass was counted during the 10 years' observations and Table 3 is a summary of these records.

The individual masses contained from 1 to 59 eggs.

The average number of eggs per mass in the years recorded is smaller than the average number of eggs per mass found by Ficht (unpublished) in 1925 and 1926. At Wheatley, in 1925, the average egg mass contained 20.4 eggs, while at Chatham, in 1926, the average mass contained 19.6 eggs. The records were obtained from 1412 and 1502 egg masses respectively. These years were not only favourable to egg production, but for some reason the moths laid more eggs per mass than is usual.

Caffrey (4) records that in New England during the years 1917 to 1921, and for two generations a year, the egg clusters have varied in size from 1 to 162 eggs, the average number being 14.6. In New York, with the univoltine borer, the average was 14.5 in 1923, and 16.7 in 1924, while in Ohio it was 14.0 in 1923 and 15.5 in 1924.

Bottger and Kent (2) state that in southern Michigan, during the years 1926 to 1930, the average number of eggs per mass has been 17.0 for each season.

At Chatham, there was considerable variation in the number of eggs per mass from year to year. Moths did not lay as many eggs per mass in 1931 as they did in 1927 or 1934.

TABLE 3.—THE AVERAGE NUMBER OF EGGS PER MASS, CHATHAM, ONTARIO, 1927–36

Year	Average number of eggs	Year	Average number of eggs
1927	18.4	1932	16.8
1928	15.1	1933	15.1
1929	14.6	1934	17.9
1930	16.6	1935	15.4
1931	12.7	1936	15.5
Average for all years			15.8

In most years the time of season in which an egg mass is laid does not affect the number of eggs it will contain. In some years, however, as in 1932 and in 1936, the size of the masses in the last half of the oviposition period was markedly smaller than that laid during the first half of the period. This may be seen from Table 4.

TABLE 4.—AVERAGE NUMBER OF EGGS PER MASS IN FIRST HALF AND LAST HALF OF OVIPOSITION SEASON, CHATHAM, ONTARIO

Year	First half of season	Last half of season
1927	18.7	20.5
1928	14.0	15.2
1930	15.7	14 2
1931	12.1	14.1
1932	19.2	16.1
1933	15.3	15.1
1934	17.4	18.6
1935	16.3	16.0
1936	20.9	12.9
Average	15.8	16.6

It would appear also that conditions in the first half of the season in 1931 and the last half of the season in 1936 were favourable to the production of smaller egg masses.

The seasonal magnitude of oviposition may also be shown by the total number of eggs laid per 100 plants. These data are given in Table 5.

By far the largest number of eggs per 100 plants were laid in 1927. The total number of this year, however, is far below those of 1925 and 1926, the years in which the borer was at its height of activity and damage. Ficht (unpublished) secured 28,870 eggs per 100 plants per season in 1925 at Wheatley, Ontario, and in 1926 he secured 29,452 eggs per 100 plants per season at Chatham, Ontario.

The Daily Magnitude of Oviposition

The number of egg masses per 100 plants laid each night for all season is plotted for each night in Figures 1 and 2. The number of egg masses per 100 plants per night has varied from none to 60.5. The number, as will be shown later, is a function of the number of moths in flight.

The Relationship Between Flight and Oviposition

The egg laying curve naturally follows that of the flight of moths. This may be seen from comparing Figures 1 and 2, Part II, with Figures 1 and 2 of Part IV. There are, however, some variations in the two curves and these will be discussed below.

The number of eggs per female per 100 plants per night and for each season has been calculated. This value for the various years under study is summarized in Table 6.

TABLE 5.—TOTAL NUMBER OF EGGS LAID PER 100 PLANTS FOR ENTIRE SEASON, CHATHAM, ONTARIO, 1927–36

Year	Total number of eggs	Year	Total number of eggs
1927	7,117	1932	1,594
1928	1,561	1933	1,537
1929	794	1934	311
1930	1,416	1935	351
1931	337	1936	1,110
Average			1,612

The best years for egg laying were 1934, 1935 and 1936, while the worst years were 1927 and 1928. It is interesting to note that, in general, the last 3 years were probably the hottest and driest years experienced during the study while 1927 and 1928 were the coolest and with abundant moisture.

The variations in the number of eggs laid per female per 100 plants from night to night during the season is great. It has varied from 0 to 6.5 eggs. In some years the moths lay more eggs per female in the first half of the season and in some years the reverse is true. This is shown plainly in Table 7.

TABLE 6.—THE NUMBER OF EGGS LAID PER FEMALE MOTH, PER 100 PLANTS DURING SEASON, 1927–36

Year	Eggs per Female	Year	Eggs per Female
1927	4.9	1932	9 6
1928	2.5	1933	6 8
1929	7.6	1934	12 9
1930	9.0	1935	15.2
1931	5.1	1936	11·8
Average			8.5

The years 1934, 1935 and 1936 were not only the best years for egg laying, but the latter portion of these seasons was apparently more favourable for egg laying than was the first half. In 1931, the last half of the season was poorer for egg laying than was the first half.

The Effect of Temperature and Other Factors Upon Number of Eggs Laid per Female

The number of eggs laid per female per 100 plants on certain nights in the years 1928, 1931, 1934, 1935 and 1936, is plotted against the average temperature for the period of flight in Figure 3. Saturation deficiency and wind are also shown.

It is seen that in 1928 the number of eggs laid per female was lower than for any other year plotted. It was highest for 1936. This year had the highest temperatures of any year during the flight and oviposition period. There does not appear to be any correlation between temperature

and number of eggs laid per female per night. The same is true for humidity and wind. It would appear that the seasonal temperature acting over 24 hours per day regulated the number of eggs laid, and not the temperature prevailing at time the moths are in flight.

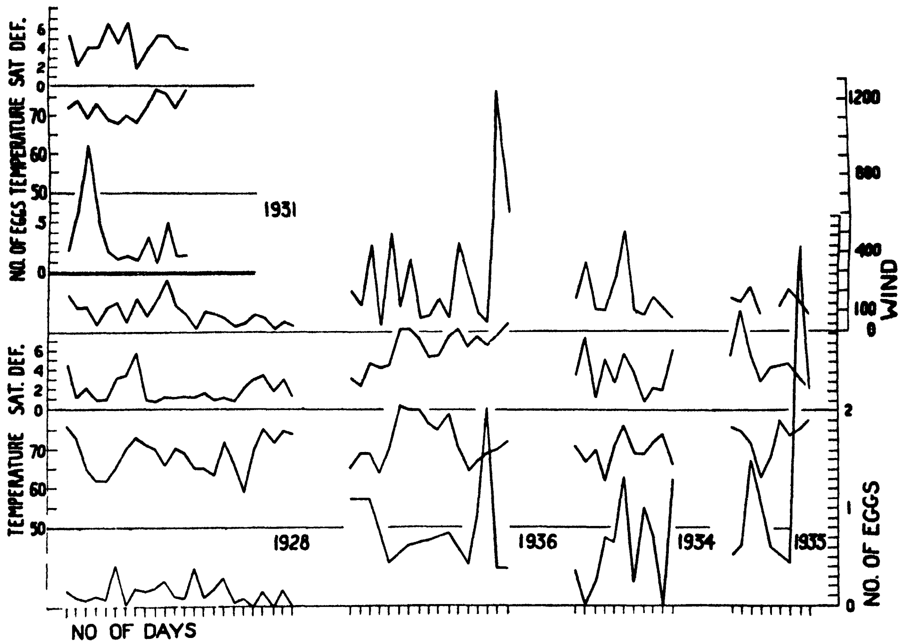

FIGURE 3. Chart showing relationship of certain physical factors to number of eggs laid per female per night.

The Increase in Number of Eggs Laid with Increase in Female Population

In general, when moths were secured in the flight plot, egg masses were secured in the establishment plot, and when moths were not secured in flight plot egg masses were not secured in the establishment plot. This association is quite striking and uniform from year to year. The apparent errors in sampling are, in most cases, very small and occur in the earlier years of work or during the early part of the season. Apparent errors are of two kinds: *(a)* where egg masses were secured, but no moths were observed in flight on that particular night; or *(b)* when moths were observed in flight, but no egg masses were found.

TABLE 7.—EGGS PER FEMALE PER 100 PLANTS PER NIGHT IN FIRST AND LAST HALF OF OVIPOSITION SEASON, CHATHAM, ONTARIO, 1927–36

Year	First half of season	Second half of season
1927	.36	36
1928	.28	38
1930	1.14	1 65
1931	.45	21
1932	.86	.83
1933	.60	.41
1934	.64	.80
1935	.88	1.73
1936	.78	.82

If the very minor errors of sampling of less than one egg mass per 100

plants per night, or less than 2 moths per night be disregarded, the apparent inaccuracies are very small in number.

Eggs, but no moths, were secured on the following nights: July 19, 1927; July 8 and July 10, 1928; July 18, 1929; July 22, 1930; July 3, 1931; and July 2, 1933. July 19, 1927, July 18, 1929 and July 2, 1933, were cold nights and below the temperature for flight to take place; moths did, however, fly and laid eggs unobserved by us.

On July 8 and July 10, 1928, only two observation periods were patrolled and the operator was in error in leaving at such an early period as moths must have flown later in the night. July 22, 1930, was a night near the end of the flight period and only two observational periods were patrolled. Moths flew later in the evening. At the same hours on ensuing nights, moths were not secured except on July 24 and so the operator was correct in his surmise that flight was terminating.

July 3, 1931, is the only night in which meteorological factors for flight and observation patrols were normal in every way. Four observations were taken and no moths secured; flight did take place, however, in plot B. On this night, therefore, moths were present in the establishment plot and in plot B, but not present in plot A.

The apparent error of having moths in the plot but no egg masses is not serious, as moths may not have laid eggs although they were present in the field. Moths were observed in the field, but no eggs were secured on July 22 and July 28, 1932; July 10, 12 and 15, 1933; July 3 and July 19, 1934. July 28, 1932, and July 10, 12 and 15, 1933, were cold nights and the temperature was 58° F. or 59° F. at 1:30 Sunset time; flight would terminate very quickly as the temperature dropped further below the minimum required for moth activity during the course of the night. These records suggest that low temperature may affect egg laying more quickly than flight.

No peculiarity of the night which would cause moths not to lay eggs can be seen from the records of July 22, 1932, July 3 and July 19, 1934, although during flight on July 19, 1934, avery heavy rain occurred. It rained at the rate of 0.04 inches per hour.

From the above data and discussion, it would appear that when the temperature was in the neighbourhood of 57° F. to 59° F., there was some factor or factors operating which caused an inaccuracy in sampling in the flight and oviposition studies. The error is not serious.

There is a general agreement between the number of females in flight and the number of egg masses laid per 100 plants per night. This is shown in Table 8.

The lowered average for classes 30–40 and 40–50 are, no doubt, due to the few samples available. By far the most accurate records are those between 1 and 30 moths as for these there are many samples.

TABLE 8.—SHOWING RELATION BETWEEN EGG MASSES LAID PER 100 PLANTS AND NUMBER OF FEMALE MOTHS IN FLIGHT, PER NIGHT, 1927–1936

The number of females in flight	Average number egg masses laid
1 - 10	2.2
10 - 20	4.9
20 - 30	16 0
30 - 40	6.7
40 - 50	11.4
75 - 100	27.1
100 - 200	30.9

From these records, it can be seen that there is an increase in the number of egg masses laid with an increase in the number of females in flight. The increase is not a direct one. This may be due to the methods of sampling moths and eggs, or it is quite probable that a number of the moths in flight each night do not lay eggs. The percentage of non-laying moths may increase more rapidly than those laying eggs. Caffrey (4) has shown that under insectary conditions moths do not lay eggs during 30% of their oviposition period. This may also be true in the field and if so, would help to explain the phenomena discussed above.

The average number of egg masses laid per 100 plants for the class 1–10 females per night for each year is interesting as it shows that the same number of moths did not lay the same number of eggs each year.

TABLE 9.—AVERAGE NUMBER OF EGG MASSES LAID BY FROM 1–10 FEMALES PER 100 PLANTS PER NIGHT, 1927–1936

Year	Average number of egg masses	Year	Average number of egg masses
1927	1.8	1932	3.0
1928	1 0	1933	1.7
1929	2.4	1934	1.0
1930	4.9	1935	2.8
1931	1 2	1936	3.2
Average			2.2

From these records it would appear that 1930 was the best year for egg laying, followed by 1936 and 1932. Before evaluating the years, however, the number of eggs per mass has to be considered. This has been done in Table 6, which shows the true relationships of the various years in regard to egg production.

Eggs have been found in the field before, on the same date, and later than the date of first moths, but the variation in time of discovery was within a day or two. In most years, moths and eggs have been found upon the same date.

The dates of peak of flight and of egg laying do not coincide, the peak of oviposition being later by a varying number of days, each year.

TABLE 10.—SHOWING RELATIONSHIP OF PEAK OF FLIGHT AND PEAK OF OVIPOSITION CHATHAM, ONTARIO, 1927–1936

Year	Date of apparent peak of flight	Date of apparent peak of oviposition	No. of days oviposition peak is after flight peak
1927	July 12	July 14	2
1928	July 16	July 20	4
1929	July 7	—	—
1930	July 8	July 13	5
1931	July 9	July 6	3 before
1932	July 7	July 16	9
1933	June 29	June 30	1
1934	July 12	July 13	1
1935	July 11	July 13	2
1936	July 9	July 11	2
Average date	July 9	July 16	3

There is also a seasonal variation in the number of days necessary to arrive at the peaks of flight and oviposition as is shown in Table 11. It can be concluded from these data that in some years the type of season is equally favourable to the development of flight and oviposition as in the years 1933 and 1934, while in others it would appear that the season was earlier more favourable for oviposition than for flight. This was the case in 1931 and to some extent in 1936. In the other years, 1927, 1928, 1930, 1932, and 1935, the season would appear to have been earlier more favourable to flight than to egg laying.

The abruptness with which the egg laying curve in 1933 reaches a peak is in marked contrast to the smoother more gradually rising curve of flight.

The Position on the Plant in Which Eggs Are Laid

As pointed out in the review of literature, it was not known until about 1919 that the eggs were deposited upon the under surface of corn leaves. Caffrey (4) states that eggs are usually laid on the under surface of corn leaves, but that they are sometimes laid upon the upper surface of the leaf, on culms, or more rarely on the husks of the ears. Spencer (17) in Elgin county, Ontario, in 1921 and 1923, found that the majority of the eggs were laid on the under surface of the leaf but that in 1922 they were frequently found on the upper surface. He claimed that eggs laid on the upper surface were killed by sunlight and did not hatch. Huber (10) found in 1927 that in Ohio 86.8% were laid on the under surface of the leaf.

TABLE 11.—THE RATE AT WHICH FLIGHT AND OVIPOSITION PEAKS ARE REACHED AFTER THEIR COMMENCEMENT

Year	No. days required—flight	No. days required—oviposition
1927	4	7
1928	9	14
1929	3	—
1930	9	14
1931	9	3
1932	9	19
1933	5	4
1934	13	14
1935	6	9
1936	11	8
Average	8	10

The position in which eggs are laid is of importance in influencing egg mortality from natural causes such as sunlight or mechanical dislodgment. Huber (10) has shown the mechanics and the ease by which egg masses may be dislodged from leaves. The position in which eggs are found is also of importance in the application of control measures, as sprays to kill the eggs must be directed upon them.

Eggs have been found by us in three positions on the corn plant: *(a)* on the under surface of leaves,

TABLE 12.—THE POSITION IN WHICH EGG MASSES ARE LAID UPON THE CORN PLANT. PERCENTAGE OF TOTAL EGG MASSES PER SEASON, CHATHAM, ONTARIO, 1927–36

Year	Lower surface of leaf	Upper surface of leaf	Culm
1927	95.7	2.8	1.5
1928	97.6	1.2	1.2
1929	93.2	6.8	0.0
1930	98.1	1.9	0 0
1931	94.0	6.0	0.0
1932	86.5	10.7	2.8
1933	95.9	4.1	0.0
1934	92.0	8.0	0.0
1935	93.4	6.6	0.0
1936	98.0	2.0	0.0

(b) on the upper surface of leaves and *(c)* on the culm or stalk. The percentage of eggs found in these locations in various years is given in Table 12.

Egg masses at Chatham are usually laid upon the lower surface of the corn leaf. A few each year are laid upon the upper surface, but only rarely are they laid on the culm. A larger percentage is laid on the lower surface of the leaf than was the case cited by Huber in Ohio in 1927.

The Length of the Incubation Period

Huber (10) has reported that the length of the incubation period under insectary conditions in Ohio in 1927 varied from 4.7 to 10.5 days, with an average duration of 7.5 days. Caffrey (4) at Silver Creek, New York, found the period to average 6.3 days in length in 1923 and 6.4 days in length in 1924. These determinations were also made under insectary conditions. Poos (15) also working in Ohio, under insectary conditions, found the period varied from 4 to 9 days, with an average duration of 5.4 days. Bottger and Kent (2) measured the length of the incubation period in caged material in southern Michigan and obtained the following records:

Year	*Average duration in days*	*Year*	*Average duration in days*
1926	6.2	1929	6.4
1927	6.1	1930	5.6
1928	5.9	Average	6.1

The incubation period was measured in the field at Chatham. The observations were made each day except in 1935 and 1936 when they were made every other day, thus leaving a choice of one day in the duration of period.

The incubation period as determined in the field is very close to that found by other workers under insectary conditions in various parts of North America. The average duration has been uniform in length for the 9-year period.

TABLE 13.—LENGTH OF INCUBATION PERIOD IN DAYS, CHATHAM, ONTARIO, 1928–1936

Year	Shortest duration	Longest duration	Average duration
1928	4	10	7.1
1929	4	9	6.1
1930	3	8	6.1
1931	4	8	6.6
1932	2	12	6.4
1933	2	8	7.0
1934	5	8	6.5
1935	5 or 6	7 or 8	6.2 or 7
1936	3 or 4	9	5.4 or 6.2
Average	3.5 or 3.7	8.7	6.3 or 6.5

EGG MORTALITY AND SURVIVAL

Review of Literature and Summary

The factors causing egg mortality are very inadequately known. The only fundamental work upon factors causing egg mortality is that of Springer (18) on the effect of ultra violet light.

The factors which have been suggested as influencing egg mortality may be grouped into two main groups:

(a) Biotic factors, including degree of fertility, predators and parasites.

(b) Physical and mechanical factors, including high temperature, low humidity, desiccation, light and mechanical dislodgment from leaf.

Fertility of Eggs

The actual number of eggs which were not fertilized and therefore did not hatch is very difficult to determine from the literature, as the term "fertility" has apparently been used loosely. Spencer (17) working in Ontario in 1921 and 1922, under insectary conditions, found that 100% of the eggs under observation hatched in 1921 and 99% hatched in 1922. Caffrey (4) states that 91.5% of the eggs deposited in the insectary and 95.4% of those in the field were fertile. These determinations were made with the bivoltine type of borer. Poos (15) in Ohio, found that 98% of eggs in insectary and 99.3% in the field hatched in 1924. Huber (10) in Ohio, states that 97.9% are fertile. Bottger and Kent (2) found that under insectary conditions during 1926 to 1930, in southern Michigan, 94.9% of eggs were fertile. Hergula (9) on the other hand, found that only 65.9% of the eggs observed by him hatched in an insectary in Hungary.

If an average is taken of the North American records, it is found that 96.2% of the eggs hatch.

Predators and Parasites

Huber (10) is the only author giving data on egg mortality from this cause in the field. He found that 2.8% of eggs were destroyed by predators No figures are available for the number of eggs killed by parasites.

Temperature and Humidity

High temperatures, low humidities and desiccation have all been suggested as causing egg mortality. Huber (10) has, in a manner, shown that desiccation kills eggs, but no experimental work has been done. Springer (18) found in his work on ultra violet light that a temperature of 90° F. for 30 minutes killed 37% of eggs.

Light

Light has been suggested as a cause of death of eggs, but no work except Springer's has been done to determine whether the killing agency is light or heat or both. Spencer (17) as early as 1922, claimed that egg masses laid upon the upper surface of leaves were exposed to sunlight and consequently killed. Caffrey (4) also records that eggs exposed experimentally to the direct rays of sun failed to hatch, but no details are given. Flint (8) makes the statement that in Ohio 3 times as many eggs were laid in 1930 as in 1929, but that drought (dry, hot weather) withered and coiled the corn leaves exposing eggs to direct rays of sun and killing them. Springer (18) studied the effect of ultra violet light upon corn borer eggs and found that an exposure of 30 minutes killed 63% of the eggs.

Mechanical Dislodgment from Leaf

Huber (10) suggests that as the leaf rolls and unrolls in response to climatic factors, the motion of the leaf tends to loosen the egg mass and causes its dislodgment. High temperatures, wind and lashing movement of leaves in wind, facilitate the process. He found that 11.2% of eggs were dislodged in Ohio.

Davis (6) claims that the season of 1934 definitely set back the borer several years in the drought areas of the central west. The hot, dry winds

in the early season resulting in the curling of corn leaves and the dislodgment (peeling) of egg masses while continuous dry weather was very destructive to the young larvae.

Egg Mortality and Survival at Chatham

Egg mortality for the purposes of presentation has been divided into two divisions: *(a)* egg mortality caused by dislodgment of egg mass from the plant and *(b)* mortality in egg masses remaining upon the plants. In reality the egg mortality from dislodgment is perhaps not egg mortality in its true sense as eggs may hatch even if dislodged. What actually happens to eggs dislodged from plant is not known. Bartley and Scott (1) determined that for egg masses dropped experimentally to ground only 6% of the larvae were able to find the corn plant and mature. For the purposes of this paper, eggs dropping from plants are regarded as dead and counted as egg mortality.

Mortality and Survival from Dislodgment

The mortality (loss) of eggs due to dislodgment is shown at Chatham in Table 14. On July 13, 1932, a local hail storm lacerated the leaves of corn in our plots. At the time of its occurrence, 12 egg masses were on the plants being observed and 7 were destroyed by the storm. The 7 masses contained 76 eggs. The storm destroyed 58.3% of the egg masses, and 9.9% of the eggs laid during the entire season. If the storm had not occurred the egg mortality for the season due to dislodgment of eggs would have been 16.6%.

TABLE 14.—EGG MORTALITY AND SURVIVAL DUE TO DISLODGMENT OF EGGS FROM PLANTS, PERCENTAGE OF TOTAL EGGS LAID

Year	No. egg masses dislodged	No. eggs dislodged	Per cent mortality	Per cent survival
1928	1	11	1.0	99.0
1929	4	43	6.6	93.4
1930	3	35	3.9	96.1
1931	1	6	2.6	97.4
1932	11	204	*26.5 (16.6)	73.5 (83.4)
1933	6	101	11.7	88.3
1934	3	46	34.0	66.0
1935	2	39	13.6	86.4
1936	3	19	2.4	97.6

* In 1932, as pointed out below, a local hail storm lacerated corn leaves, causing an increased mortality. The figure in brackets indicates what the mortality would have been if the storm had not occurred.

The Time of Season in Which Egg Masses Were Dislodged

The number of egg masses falling from plants is so small that little can be ascertained about the conditions causing them to fall. In 1928, one egg mass fell on July 11. In 1929, egg masses fell off on July 16, July 25 (2) and July 29. In 1930, they fell off July 10 and July 28 (2). In 1931, on July 5. In 1932, on June 29, July 6, July 13 and July 21. In 1933, on June 30, July 1, July 2, July 7, July 8, July 16. In 1934, on June 30 and July 13 (2). In 1935, on July 17 and July 23. In 1936, on July 19 (2) and July 22.

Two masses fell off on July 25, 1929; July 28, 1931; July 13, 1934; July 19, 1936. This might indicate that conditions at these times were favourable for egg mass dislodgment. The days under discussion in 1929, 1931 and 1934, were not particularly warm, but it rained on each one. July 19, 1936, was a very hot day, the temperature reaching 102° F. in the shade. Under this condition, corn would be wilted.

The Egg Mortality Upon Plants

The mortality of eggs remaining upon plants is smaller than that caused by eggs falling from plants. This may be seen from Table 15.

TABLE 15.—MORTALITY AND SURVIVAL OF EGGS REMAINING UPON PLANTS. PERCENTAGE OF TOTAL EGGS LAID FOR SEASON

Year	Mortality	Survival	Year	Per cent Mortality	Per cent Survival
1928	3 7	96 3	1933	5 6	94 4
1929	2 0	98 0	1934	0 0	100 0
1930	6 0	94 0	1935	8 1	91 9
1931	7 7	92 3	1936	11 6	88 4
1932	7 6	92 4	Average	5 8	94 2

The causes of the above mortality are not known. It is not, however, due to parasites or predators as the eggs were examined daily with a hand lens. The eggs failing to hatch were intact, but sometimes shrivelled and cometimes of a brownish colour. Infertile eggs were not distinguished. Only rarely was it that an entire egg mass failed to hatch.

This egg mortality occurred at various times during each season. The following is a record of the date upon which egg masses were laid and which experienced mortality. Each date represents an egg mass. When there are more than one on a single day, the number of masses is indicated in brackets. In the year 1928, July 11, 14, 15, 17, 18 (3). In 1929, July 4-14 (2), 21, 23, 25. In 1930, July 1, July 4 (2), 6 (4), 8, 13 (2), and July 16. In 1931, July 12. In 1932, June 30, July 9, 10, 11, 12, 13, 15, 16 (3), 27, 28, 31. In 1933, June 27, June 29 (6), July 1 (2), 5, 18, 26. In 1935, July 13 (2), 15, 21, 23, 31. In 1936, July 3, 5, 9, 11 (6), 13, 15 (3), 16, 17 (5).

The Mortality of Egg Masses Deposited on Upper Surface of Leaves

As has been shown and discussed above, a number of workers have observed that eggs exposed to direct sunlight are killed.

The number of egg masses laid on the upper surface of leaves during our observations has been small. Only 34 masses were laid on the establishment plot proper where detailed records of hatching were observed.

Only one mass was dislodged from the leaf. The mortality of eggs in masses remaining on the leaves was only 6.7% and the total mortality

counting the mass that fell off, during the 9 years was 15.2%. The egg mortality under our conditions was about the same in eggs laid on the upper surface as it was in those laid on the lower surface.

The Total Egg Mortality and Egg Survival

The egg mortality from all causes and based upon the total number of eggs laid during the season is shown in Table 16. In 1932, the mortality and survival are given with the hail storm mortality included, and in brackets the mortality as it would have been if the hail storm had not occurred.

Egg mortality was highest in 1934. It occurred by dislodgment of masses from plants as all eggs remaining on plants hatched. The lowest egg mortality occurred in 1928. The physical factors operating in these years will be discussed below.

TABLE 16.—TOTAL EGG MORTALITY AND SURVIVAL, CHATHAM, ONTARIO, 1928–1936, IN PERCENTAGE OF TOTAL EGGS LAID DURING SEASON

Year	Per cent mortality	Per cent survival
1928	4.8	95.2
1929	8.6	91.4
1930	9.8	90.2
1931	10.2	89.8
1932	32.2 (22.3)	67.8 (77.7)
1933	16.8	83.2
1934	34.1	65.9
1935	20.8	79.2
1936	13.9	86.1
Average	16.8 (15.7)	83.2 (84.3)

LARVAL MORTALITY AND SURVIVAL IN ESTABLISHMENT

A Review of the Literature

The literature referring to actual larval mortality and survival is not extensive. Usually, total mortality and survival of the egg and larval stages are considered together. An attempt is made to keep the two subjects separated for the present. Mortality and survival as a seasonal phenomenon is discussed later.

Spencer (17) working in Elgin county, Ontario, was the first to note and describe the enormous death rate of the larvae after hatching. In this case all of the eggs under observation hatched and egg mortality was not a factor. Spencer attempted to record the activities of larvae on corn plants immediately after hatching. He found that in 6 hours only 4 larvae out of 39 could be traced and were known to have remained upon the plant. Approximately one-tenth of all larvae remained on the plant; the others died or were blown from the plant. Some larvae curled up and died, without any apparent reason, within a few seconds after hatching.

Caesar (3) also working in Elgin county in 1924, studied larval mortality on four corn varieties. Here again there was no egg mortality and the results give larval mortality only. He found that the average mortality was 78.2% or a survival of 21.8%; 76.2% of the mortality occurred in the first two larval instars when the larvae were less than 10 days old. The factors responsible for larval mortality were not determined, but heavy rains, wind and other climatic factors and their seasonal variations were suggested as causes.

Painter (unpublished) studied the seasonal larval mortality at Harrow, Essex county, Ontario in 1923. He found that the average mortality for

3 types of corn was 84.4% or a survival of 15.6%. Painter and Ficht (13) repeated the work in Elgin county in 1924 and found the average mortality for the same 3 types of corn to be 80% which is a survival of 20%. They found that 75% of the mortality occurred in the first two larval instars "when the larvae were attempting to establish themselves". This is the first use of the term "establishment".

The causes of the death of larvae were not determined, but they noted that first instar larvae were quite helpless in a film of water and that many were drowned in the water present in the "throat" of the plant. They also found many larvae pinched to death between the surfaces of the leaves in the "throat" of the plant.

Caffrey (4) reported on work carried out at Sandusky, Ohio, in 1924. The larval mortality was 91.6% for the corn varieties studied. His work also showed that most of the mortality took place during the first 2 instars. He suggested that mortality was brought about by a variety of causes, the most important of which seemed to be desiccation, starvation and drowning.

Huber (10) pointed out that the meteorological factors, at the time the larvae are hatching and while they are yet outside the stalk, have a very important bearing upon the percentage of larvae becoming established. Fitful winds blow larvae from the plant, while stronger winds favour establishment because the larvae cling to the leaf surface. If, however, the temperature is low, about 60° F., the larvae are unable to cling to leaf surface for very long and they blow off. Dashing rains are also said by Huber to be destructive to larvae. He claims that still water in axils of leaves is harmless. This is contrary to the opinion of Painter and Ficht, noted above. The present writer has often noted numbers of dead larvae in the water in the axils of the leaves and assumed they had drowned. They might have blown in after dying on the leaf surface.

Roubaud (16) has shown that newly hatched larvae are extremely sensitive to dehydration. In a humid atmosphere, he found larvae would live a day comfortably without food, but if placed in a dry place they became sluggish and soon died.

Thompson and Parker (19) state that in the lower Rhone valley in Europe the corn fields are swept by a constant wind known as the "mistral". Only a slight corn borer infestation develops in this valley and it is thought that the reduced infestation is due to the effect of the wind on the adults and young larvae.

The above review indicates that larval mortality and survival varies somewhat, depending upon a number of biotic and climatic factors, and varies from 75 to 80% mortality or a survival of 20 to 25%. Various physical and climatic factors have been suggested as the causes of larval mortality, but no one has actually determined the causes.

Larval Mortality at Chatham

Larval mortality has been studied and measured in the field during the past 9 years. Table 17 shows the mortality and survival obtained. The actual larval mortality has varied from 92.4% in 1930 to as low as 42.8% in 1931. The average larval mortality has been 72.1%.

It has been shown by Caesar (3), Painter and Ficht (13), Caffrey (4) and others that mortality takes place immediately after the larvae hatch and before they enter the plant. The time of season in which larvae hatched in each year is shown in some detail later.

TABLE 17.—LARVAL MORTALITY AND SURVIVAL IN ESTABLISHMENT, CHATHAM, ONTARIO, 1928–1936

Year	No. eggs hatching	No. larvae recovered	Per cent larval mortality	Per cent larval survival
1928	1041	455	56.2	43.8
1929	588	106	81.9	18.1
1930	795	60	92.4	7.6
1931	203	116	42.8	57.2
1932	522	129	75.2	24.8
1933	717	151	78.9	21.1
1934	89	25	71.9	28.1
1935	226	110	51.3	48.7
1936	667	203	69.5	30.5
Average			72.1	27.9

The Effect of the Physical Factors upon Larval Mortality and Survival

Wind, rain, and hot dry periods are among the physical factors suggested by various authors as causing high larval mortality. It is shown later that these three factors have not influenced the percentage of larval mortality to any extent at Chatham. Sudden heat waves have been the main factor causing larval mortality. A detailed discussion is given later.

TOTAL MORTALITY AND SURVIVAL

Egg and larval mortality and survival have been discussed individually above. They will now be discussed as total mortality and survival based upon the total number of eggs laid.

There are a few additional papers dealing with this phase of the study. Marshall (12) studied the total mortality at Aylmer, in Elgin county, Ontario, in 1926, by artificially infesting plants with egg clusters. He obtained an average mortality of 86.6% or a survival of 13.4%. Marshall was the first to attempt to show a correlation between total mortality and field infestation in the neighbourhood of his experimental plots. He utilized his own records and those of Caesar and others taken in Elgin county. He concluded that a high mortality foretells a decrease in field population.

Caffrey (4) states that in 1924 in northern Ohio, in caged experiments, the total mortality was 94.1%.

Patch (14) shows that at Sandusky, Ohio, the total mortality in all varieties of corn studied was 66% in 1927 and 64.4% in 1928. Thsee are survivals of 34 and 35.6% respectively. He points out that these figures are much lower (mortality) than the 85% average mortality obtained in previous years.

Ficht (7) gives the seasonal mortality for three varieties of corn grown at Monroe, Michigan, during certain years. The following summary

showing the percentage mortality has been arranged from a portion of his data.

Variety of Corn	*1928*	*1929*	*1930*
Clements White Cap	83.0	78.9	92.7
Johnson County White	84.6	81.5	94.6

The mortality and survival on these varieties at Monroe, Michigan, are practically identical with those obtained on Wisconsin No. 7 corn at Chatham during 1929 and 1930. The season of 1928 was much more favourable for borer survival at Chatham than it was at Monroe. This may be determined by comparing the results at Monroe with those obtained at Chatham as shown in Table 18.

TABLE 18.—TOTAL MORTALITY AND SURVIVAL, WISCONSIN NO. 7 CORN, CHATHAM, ONTARIO, 1928–36

Year	Total no. eggs laid	Total no. eggs hatching	Per cent egg mortality	No. larvae recovered	Per cent larval mortality	Per cent total mortality	Per cent total survival
1928	1093	1041	4.8	455	56.2	58.3	41.7
1929	*643	588	8.6	106	81.9	83.5	16.5
1930	881	795	9.8	60	92.4	95.4	4.6
1931	226	203	10.2	116	42.8	48.6	51.4
1932	769	522	32 2	129	75 2	83 2	16.8
1933	861	717	16.8	151	78.9	82.4	17.6
1934	135	89	34.1	25	71.9	81 4	18.6
1935	285	226	20.8	110	51.3	61.4	38.6
1936	774	667	13.9	203	69.5	73.7	26.3
Average			16.8		72.1	76.1	23.9

* The total eggs laid for this season was 765. Only a portion of these, namely, 643, were used for establishment records.

(To be continued)

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DIGESTIBILITY STUDIES WITH RUMINANTS.

III. PLANE OF NUTRITION AND DIGESTIBILITY OF MANGELS

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[Received for publication January 31, 1938]

In the first paper of this series on *Digestibility Studies with Ruminants* (1) four factors which required study were listed. These were: *(a)* plane of nutrition; *(b)* associative effects; *(c)* age of animal; and *(d)* species. The first two, namely, plane of nutrition and associative effects are interrelated. Consider, for instance, a two-component ration such as hay and a succulent. If the hay is fed at a constant level and the quantities of succulent varied, then, not only will there be a change in the plane of nutrition, but there will also be a change in the ratio of succulent to hay.

The complete investigation of this condition requires: *(a)* a calculation of the digestibility of the succulent at each level of feeding with the hay kept at a constant level; *(b)* a determination of the effect of the plane of nutrition upon the digestibility of rations of hay and the succulent in which the components are in constant ratio to one another, several experiments being undertaken in which different ratios are used; and *(c)* a determination of the effect of the plane of nutrition upon the hay alone and the succulent alone. Depending upon the outcome of any one of these factors, it may or may not be necessary to investigate all three of them.

Two combinations have been studied in this way, namely, hay and corn silage, and hay and mangels. In the case of the former it was necessary to investigate all three factors. In the case of the latter, however, that has not been deemed necessary. The present paper reports the results with the hay and mangels combination, while the results with silage will be published later in a series of papers.

Before discussing the actual experiments, certain points in technique require explanation. These refer, first, to the method of conducting *ad libitum* feeding trials, and second, to the method of preparing mangels for a chemical analysis.

In conducting *ad libitum* feeding trials, roots at a level of 50 kilogrammes per animal per day were added to a constant hay ration up to and including the morning feeding of the first day of the collection period. They were then fed *ad libitum* up to and including the morning feeding of the fourth day before the end of the collection period. From this point, the level of roots was reduced to the 50 kilogrammes per day originally fed.

Two assumptions were made in conducting trials in this manner. The first was that not more than four days were required until the fecal excretion corresponded to the ration fed. The second was that the time required for the fecal excretion to correspond to the ration in going from the 50 kilogrammes to the *ad libitum* was the same as that required in going from the *ad libitum* to the 50 kilogrammes. Even if these assump-

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tions were not exact, the error must have been very slight since the level of 50 kilogrammes was close to the *ad libitum* feeding.

It is true, however, that apart from the operating difficulties in carrying out such a trial, the method itself does not, theoretically, conform to recognized good practice in conducting digestibility trials. For dry feeds, therefore, the maximum constant level which can be consumed should be ascertained in the preliminary period and that level fed throughout the trial. The *ad libitum* feeding is perhaps more justified with roots or succulents since there is, in any case, a variation in dry matter content of the daily rations, thus prohibiting a constant intake throughout the experiment.

To prepare air-dry samples of roots for analysis, care must be taken to avoid losses of "soluble carbohydrates" through enzymatic action. In an oven at 70° C., the temperature of the root cuttings does not apparently reach a sufficiently high degree in the initial stages to inhibit this enzymatic action. This is indirectly illustrated in the following experiments.

Dry matter determinations were made on cuttings of mangels under the following conditions: *(a)* dried at 100° C. to a constant loss; *(b)* dried for 18 hours at 70° C. followed by drying at 100° C. to a constant loss; and *(c)* procedure *(b)* with the roots first treated with chloroform to eliminate bacterial action. The results are given in Table 1.

TABLE 1.—DRY MATTER CONTENTS OF MANGELS AS DETERMINED BY DIFFERENT PROCEDURES

Sample No.	Dry matter contents		Differences
	At 100° C.	Preliminary at 70° C.	
	%	%	
1	10.75	10.24	+0.51
2	10.77	9.00	+1.77
3	11.29	10.38	+0.91
4	9.55	9.29	+0.26
5	10.30	10.08	+0.22
6	11.61	8.23	+3.38
7	11.15	10.93	+0.22
8	11.11	8.71*	+2.40
9	11.08	10.17*	+0.91
Means	10.85	9.67	+1.176

* Treated with chloroform. $t = 3.162$.

It will be noticed from Table 1 that when the roots were placed in the oven at a temperature of 70° C. there was a loss of dry matter. Enzymatic action presumably caused this loss since the treatment with chloroform in the two cases tried did not affect the results. The magnitude of the losses showed considerable variation depending possibly upon the position in the oven and the rapidity of drying. Using Fisher's t test, however, the differences were statistically significant.

To serve as a check on the oven drying method at 100° C., dry matter determinations were made on the roots by means of the xylene distillation method. The results are expressed in Table 2.

In 6 out of the 9 comparisons, the results with the xylene distillation method were slightly higher than with the oven drying. The mean of the dry matters determined by the xylene method was slightly higher than the mean determined by the overn drying. The difference, however, was not statistically significant.

This tendency for the xylene method to give slightly higher results might be due in part to a loss of a small amount of water either in the

condenser or entrained with and carried back by the xylene to the distillation flask. This flask was of 1-litre capacity, and 300 to 400 cubic centimetres of xylene on 120 grammes of roots were used. A loss of 0.19 cc. of water would produce the differences in dry matter content shown in the table above. These differences may also be due in part to occasional losses of dry matter even at 100° C. It was felt, however, that these results substantiated the trustworthiness of the oven drying at 100° C. and that, therefore, the results obtained by a preliminary drying at 70° C. were too low.

TABLE 2.—DRY MATTER CONTENTS OF ROOTS DETERMINED BY OVEN DRYING AT 100° C. AND BY XYLENE DISTILLATION

Sample No.	Dry matter contents		Differences
	At 100° C. in oven	Xylene distillation	
	%	%	
1	10.16	10.34	−0 18
2	9.83	10.39	−0.56
3	10.13	10.71	−0.58
4	9.94	9.72	+0.22
5	9.90	9.85	+0.05
6	10.07	10.18	−0.11
7	9.40	9.78	−0.38
8	9.80	9 65	+0.15
9	9.66	9.73	−0.07
Means	9.88	10 04	−0.162

$t = 1.675$.

For preparing samples of roots, other succulents, and feces for analysis, therefore, the following procedure was adopted. The samples in large shallow enamel trays were placed in an oven at 100°C. for 1½ to 2 hours to inhibit enzyme action. They were then placed in the oven at 70° C. and brought to dryness. It should be pointed out that water in a flat dish in the oven at 100° C. reached a temperature of approximately 70° C. in three-quarters of an hour and remained constant at that temperature. It was felt, therefore, that this preliminary treatment of the samples was sufficient to prevent enzyme action.

Even under these conditions there seems to have been a slight loss or slight decomposition of the "soluble carbohydrates". The nitrogen contents of the roots calculated from the analyses of the air-dried samples were always slightly higher than the nitrogen contents calculated from determinations on the original samples. In the calculation of the coefficients of digestibility, the analyses of the air-dried samples have been used as the basis.

EXPERIMENTAL PROCEDURE

The experimental animals consisted of four grade Shorthorn steers, numbered in the experiment A, B, C and D, with average weights for the whole experiment of 489, 497, 447 and 444 kilogrammes respectively. Nine rations were fed, namely, hay alone, mangels alone, and mixtures of mangels and hay in which the hay was kept constant at 4 kilogrammes per animal per day and the mangels were fed at levels of, 5, 10, 16, 22, 35, 50 and *ad libitum* kilos per animal per day. The experiment lasted 18 months and consisted of 12 periods. The first 7 periods were carried out in 1935–36 and the last 5 in 1936–37. Between these two seasons the animals were placed on pasture for three months. The same hay was used throughout the entire experiment. It was necessary, however, to use mangels from

two crops. They were, nevertheless, from the same locality, of the same variety, and grown as far as possible under similar conditions. The schedule of the experiment is given in Table 3.

TABLE 3.—SCHEDULE OF EXPERIMENT (WEIGHTS IN KILOGRAMMES PER DAY)

Period No.	Feeding stuff	Fed per day per animal			
		Animal A	Animal B	Animal C	Animal D
1935–36					
1	Hay Mangels	4 5	4 10	4 16	4 22
2	Hay Mangels	4 61*	7.5 0	0 28	4 5
3	Hay Mangels	4 10	4 50	4 22	4 52.2*
4	Hay Mangels	7.5 0	0 40	4 35	4 10
5	Hay Mangels	4 50	4 22	4 54.2*	7.5 0
6	Hay Mangels	0 40	4 35	4 10	4 50
7	Hay	—	—	7.5	—
1936–37					
8	Hay Mangels	7.5 0	4 16	4 50	0 40
9	Hay Mangels	4 22	7 5 0	0 40	4 35
10	Hay Mangels	0 40	4 5	7.2 0	4 16
11	Hay Mangels	4 16	4 58.3*	4 5	7.5 0
12	Hay Mangels	4 35	0 40	— —	0 40

* *Ad libitum* feeding of mangels.

It will be observed from Table 3 that each animal received each hay-mangel ration once, and each of the rations of hay alone or mangels alone, twice. Iodized rock salt was given *ad libitum* in the preliminary periods and iodized granulated salt in the collection periods at a rate of 20 grammes per animal per day for all rations containing roots, and at a rate of 30 grammes per day for the hay rations.

Each complete digestion trial lasted 28 days. The first four days constituted the pre-experimental feeding, the ensuing twelve were the preliminary, and the final twelve the collection. During the pre-experimental feeding, the animals received a good ration of hay, mangels, and

3 kilos of the following grain mixture: ground oats 400, ground barley 300, gluten meal 100, wheat bran 100, oil cake 100, bone char 20 and salt 10. The animals were also exercised at this time. When a collection period of 16 days was used for *ad libitum* trials, this pre-experimental period was omitted.

Dry matter and nitrogen were determined daily on the feces during 1935–36 and every 2 days during 1936–37. Dry matter was determined daily on the roots during the entire experiment and nitrogen was determined daily during 1936–37.

Sufficient hay to last the entire experiment was stored in the barn loft. For each trial, approximately three-quarters of a ton were cut in a corn cutter and thoroughly mixed. Individual daily rations for the entire trial were bagged. During the bagging, four samples of about 4 kilogrammes each were taken for analysis.

In the case of Animal C, period 10, there was a refusal of hay amounting to 4%. This took place at the beginning of the collection period, but during the latter part the animal ate its ration completely. In Table 4, the composition of the refused material is compared with that of the experimental hay.

TABLE 4.—COMPARISON OF CHEMICAL COMPOSITION OF EXPERIMENTAL HAY AND REFUSED HAY IN PERIOD 10 ON DRY MATTER BASIS

Nutrient	Refused hay	Experimental hay
	%	%
Ash	7.83	7.77
Crude protein	11.44	12.48
Ether extract	1.78	2.19
Crude fibre	39.03	36.99
N-free extract	39.92	40.57

The refused hay was slightly higher in crude fibre and slightly lower in crude protein than the experimental. Presumably, in the refused sample there was less leafy material. However, this refused material as indicated by the chemical analysis and also by its appearance quite closely resembled the original hay. It was concluded that the coefficients of digestibility determined in this case were reliable.

RESULTS

In Table 5 are given the chemical compositions of the hay for the individual periods and for the individual samples within those periods.

TABLE 5.—CHEMICAL COMPOSITIONS OF HAY IN PERCENTAGE OF DRY MATTER

Sample No.	Percentage composition									General means
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Periods 8 and 9	Periods 10, 11, 12	
Organic matter										
1	92.58	91.96	91.39	92.49	92.31	92.30	92.03	92.21	92.19	
2	92.44	91.56	92.06	92.30	92.47	92.16	91.60	91.78	91.88	
3	92.71	91.85	91.74	92.11	91.89	92.09	91.92	91.99	92.20	
4	92.31	91.35	91.77	92.06	92.14	92.15	92.03	91.90	92.63	
Means	92.51	91.68	91.74	92.24	92.20	92.17	91.89	91.97	92.23	92.071

TABLE 5.—CHEMICAL COMPOSITIONS OF HAY IN PERCENTAGE OF DRY MATTER—*Continued*

Sample No.	Percentage composition									General means
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Periods 8 and 9	Periods 10, 11, 12	
Nitrogen										
1	1.82	1.98	2.06	1.86	1.93	1.87	2.00	1.95	2.08	
2	1.91	2.17	1.89	1.96	1.88	1.98	1.92	2.06	1.96	
3	1.80	2.07	1.94	1.97	2.13	1.93	2.09	2.06	2.03	
4	1.94	2.15	1.98	2.11	1.92	1.96	2.11	2.00	1.92	
Means	1.87	2.09	1.97	1.97	1.96	1 93	2.03	2.02	2.00	1.983
Ether extract										
1	1.78	1.90	1.96	1.84	1.74	1.82	1.68	2.12	2.23	
2	1.69	1.98	1.63	1.73	1.70	1 69	1.93	2.36	2.29	
3	1.91	1.73	1.94	1.82	1.83	1.69	1.77	2 26	2 17	
4	2.11	2.00	1.90	1.96	1.83	1.67	1.82	2.21	2.08	
Means	1.87	1.90	1.86	1.84	1.78	1.72	1 80	2.24	2.19	1.910
Crude fibre										
1	39.13	37 36	35.97	38 11	39.69	37.35	36.75	38 37	37.77	
2	38.84	35 65	37 87	39 26	38.96	38.60	34.85	36.07	36.11	
3	38.59	37 82	36 67	38.26	36.74	37.55	35.96	37.45	36.54	
4	37.11	35.19	36.34	37.25	37.21	38.57	36 11	37.45	37.57	
Means	38.42	36.51	36.71	38.22	38.15	38.02	35.92	37.34	36.99	37.364
N-free extract										
1	40.27	40.34	40.56	40.92	38.80	41.45	41.13	39.55	39 17	
2	39.96	40.36	40.73	39.09	40.05	39.52	42.83	40.49	41.26	
3	40.96	39.34	41.01	39 74	40 03	40.81	41.15	39.41	40.80	
4	40.99	40.72	41.15	39.68	41.11	39 68	40.93	39.73	40.99	
Means	40.54	40 19	40 86	39 85	39.99	40.36	41.50	39.79	40.57	40.409

TABLE 6.—ANALYSIS OF VARIANCE OF CHEMICAL COMPOSITION OF HAY

For $n_1 = 8$, $n_2 = 27$ at P of 0.05, $z = 0.4176$ and at P of 0.01, $z = 0.5902$

Nutrient	Variance due to	F	Sums of squares	Variance	$\frac{1}{2}$ Log$_e$ variance	z
Organic matter	Within periods Between periods	27 8	1.3783 2.3136	0.05105 0.28920	$\bar{2}$.5125 $\bar{1}$.3797	0.8672
Nitrogen	Within periods Between periods	27 8	0.1753 0.1270	0.00649 0.01588	$\bar{3}$.4815 $\bar{3}$.9286	0.4471
Ether extract	Within periods Between periods	27 8	0.3569 1.0460	0.0132 0.1308	$\bar{3}$.8370 $\bar{2}$.9829	1.1459
Crude fibre	Within periods Between periods	27 8	25.1973 25.1145	0.9332 3.1393	$\bar{1}$.9654 0.5735	0.6081
N-free extract	Within periods Between periods	27 8	14.7685 9.4333	0.5470 1.1792	$\bar{1}$.6983 0.0823	0.3840

In Table 6 an analysis of the variance of the results is presented. The variance within the periods has been compared with the variance between the periods. With the exception of the nitrogen-free extract and perhaps the nitrogen, the variance between the periods was statistically significantly greater than the variance within the periods. This was to be expected since the portion of hay for each period was thoroughly mixed whereas the hay stored for the entire experiment was, of course, not previously mixed. The means for the periods were, however, quite uniform, showing no particular trend and revolving regularly around the general means.

In Table 7, the chemical composition of the 1935–36 crop of mangels has been compared with that of the 1936–37 crop. The means, standard

TABLE 7.—CHEMICAL COMPOSITION OF MANGELS IN 1935–36 AND 1936–37 IN PERCENTAGE OF DRY MATTER

Period No.	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
		1935–36			
1	90.18	2.14	0.51	8.30	67.99
2	89.40	2.05	0.57	7.51	68.53
3	88.85	2.28	0.92	8.48	65.19
4	89.36	2.20	0.95	8.76	65.87
5	89.45	2.21	0.78	8.09	66.80
6	89.78	2.25	0.68	8.60	66.42
Mean	89.50	2.19	0.74	8.29	66.80
Standard error	±0.18	±0.03	±0.07	±0.18	±0.52
Coefficient of variation	0.50	3.79	24.5	5.40	1.90
		1936–37			
8	88.03	2.17	0.52	9 04	64.90
9	87.37	2.16	0.49	8.94	64.47
10	88.38	2.23	0.52	9.18	64 76
11	90.82	1.94	0.51	7.27	70 94
12	90.67	1.91	0.94	7.27	70.51
Mean	89.05	2.08	0.60	8.34	67.12
Standard error	±0.71	±0.07	±0.09	±0.44	±1.48
Coefficient of variation	1.78	7.02	32.2	11.76	4.92

errors and coefficients of variation have been calculated. It is quite evident that there were no differences in chemical composition between the crops of the two years.

In Table 8, the coefficients of digestibility of the hay and mangels determined when each was the sole feed have been compared for the 1935–36 and the 1936–37 periods. The results for the two years with both feeds were quite similar. Only in the case of the coefficients of digestibility of the nitrogen of the mangels did it appear that the 1935–36 crop differed to some extent from the 1936–37 crop. It should be noted, of course, that only three values were available for the 1935–36 crop which fact made the mean somewhat unreliable as an estimate of the true value.

TABLE 8.—COMPARISON OF COEFFICIENTS OF DIGESTIBILITY OF HAY AND MANGELS FOR 1935–36 AND 1936–37

(Coefficients in per cent)

Animal No.	Feeding stuff	Dry matter		Organic matter		Nitrogen		Ether extract		Crude fibre		N-free extract	
		1935–36	1936–37	1935–36	1936–37	1935–36	1936–37	1935–36	1936–37	1935–36	1936–37	1935–36	1936–37
A	Hay	52.0	52.5	52.9	53.5	58.1	58.6	43.9	48.9	43.0	42.1	60.8	61.8
B		52.1	52.7	52.9	53.4	58.6	59.8	35.2	50.8	43.3	42.9	59.7	60.7
C		52.2	53.0	53.0	53.5	56.1	55.0	33.9	50.5	39.7	42.2	63.4	62.6
D		51.4	51.7	52.1	52.5	57.9	55.5	34.0	44.4	40.8	42.0	61.1	60.6
Mean		51.9	52.5	52.7	53.2	57.7	57.2	36.8	48.7	41.7	42.3	61.3	61.4
S.E.		±0.18	±0.28	±0.21	±0.24	±0.55	±1.17	±2.40	±1.48	±0.87	±0.20	±0.78	±0.48
C.V.		0.70	1.06	0.80	0.91	1.89	4.09	13.1	6.07	4.17	0.97	2.54	1.55
A	Mangels	87.0	87.1	87.8	88.3	76.6	73.2			57.9	65.1	94.5	95.3
B		86.7	87.3	88.7	89.4	75.3	72.2			59.8	62.3	95.8	95.5
C		85.1	84.0	86.6	85.5	79.2	73.0			25.5	46.7	95.0	94.0
D			87.0		89.0		78.4				61.7		95.3
D			84.3		86.6		65.7				48.7		94.2
Mean		86.3	85.9	87.7	87.8	77.0	72.5			47.7	56.9	95.1	94.9
S.E.		±0.59	±0.73	±0.61	±0.74	±1.15	±2.02					±0.38	±0.31
C.V.		1.18	1.91	1.20	1.89	2.58	6.24					0.69	0.74

From the results, then, of the chemical compositions and digestibilities of the hay and mangels as presented in Tables 5, 6, 7 and 8, it was concluded that the feeds were the same in both years and that the experiment could be treated as one continuous investigation.

Using the average coefficients of digestibility determined from the eight trials with hay, the coefficients of digestibility of the mangels have been calculated from the 28 mixed rations. Since in a previous publication (1) it was shown that the plane of nutrition had no effect on the digestibility of hay, then the coefficients of digestibility of the nutrients of the hay determined on the hay alone at a level of 7.5 kilogrammes per day were applicable to the four kilogrammes of hay fed in the mixed rations. The complete data will be found in Table 11 in the appendix. In Table 9, the calculated coefficients of digestibility of mangels as well as the coefficients determined directly with mangels as the sole feed have been arranged by rations and by animals. The coefficients of digestibility which were directly determined have been placed in columns M and M_1; M representing

TABLE 9.—COEFFICIENTS OF DIGESTIBILITY OF MANGELS ARRANGED BY ANIMALS AND BY RATIONS (COEFFICIENTS IN PER CENT)

Nutrient	Animal	Determined directly		Calculated from mixtures with hay							Means
		M	M_1	I	II	III	IV	V	VI	VII	
Dry matter	A	87.0	87.1	88.0	84.2	85.2	88.0	87.6	85.1	83.2	86.2
	B	86.7	87.3	94.8	86.1	90.1	85.9	84.2	83.0	83.2	86.8
	C	85.1	84.0	82.9	77.7	87.2	85.3	86.7	82.0	88.6	84.4
	D	87.0	84.3	78.2	82.5	83.1	85.4	89.7	84.4	83.8	84.3
	Means	86.5	85.7	86.0	82.6	86.4	86.2	87.1	83 6	84.7	85.41
	S.E.	±0.46	±0.88	±3.56	±1.80	±1.49	±0.63	±1.34	±0.70	±1.31	
	C.V.	1.06	2.06	8.27	4.36	3.45	1.46	2.62	1.67	3.09	
Organic matter	A	87.8	88.3	91.0	87.8	87.4	89.7	90.0	86.6	85.2	88.2
	B	88.7	89.4	96.2	90.0	92.5	87.1	84.1	85.7	85.6	88.8
	C	86.6	85 5	85.8	78.0	89 0	87.7	88.4	84.2	89.5	86.1
	D	89.0	86.6	79.6	82.9	84.6	87.0	91 1	84.9	85.8	85.7
	Means	88.0	87.5	88.2	84.7	88.4	87.9	88.4	85.4	86.5	87.20
	S.E.	±0.54	±0.87	±3.55	±2.68	±1.65	±0.63	±1.54	±0.52	±1.00	
	C.V.	1.23	1.99	8.06	6.32	3.73	1.43	3.48	1.21	2.31	
Nitrogen	A	76.6	73.2	70.4	63.6	61.7	73.1	65.3	69.1	64.3	68.6
	B	75.3	72.2	92.4	73.4	83.6	74.4	75.4	66 9	60.8	74.9
	C	79.2	73.0	66.9	74.3	75.5	70.6	71 7	62 2	68.6	71.3
	D	78.4	65.7	81.9	72.6	63.6	70.0	76.2	69.6	67.7	71.7
	Means	77.4	71.0	77.9	71.0	71.1	72.0	72.2	67.0	65.4	71.65
	S.E.	±0.88	±1.79	±5.80	±2.48	±5.17	±1.04	±2.49	±1.69	±1.78	
	C.V.	2.27	5.04	14.89	6.99	14.53	2.88	6.88	5.04	5.43	
N-free extract	A	94.5	95.3	93.9	93.5	93.3	96.2	95.9	94.3	92.7	94.4
	B	95.8	95.5	102.4	98.2	95.3	94.3	93.0	92.5	92 4	95.5
	C	95.0	94.0	95 1	92.4	94.4	93.7	94.6	91 9	95.1	94.0
	D	95.3	94.2	86.9	92.0	95.2	93.7	95.9	92.8	92 4	93.2
	Means	95.2	94.8	94.6	94.0	94.6	94.5	94.9	92.9	93.2	94.27
	S.E.	±0.27	±0.38	±3 17	±1.43	±0.46	±0.59	±0.69	±0.51	±0.65	
	C.V.	0.58	0.80	6.71	3.04	0.98	1.25	1.45	1.10	1.40	

the first cycle of the experiment and M_1 the second. The remaining columns headed by Roman numerals represent increasing quantities of mangels fed with the constant ration of hay. Columns VI and VII, representing 50 kilogramme and *ad libitum* levels, respectively, were actually very close together and the whole eight values may be taken as indicative of top levels of feeding.

The analysis of variance of these data is presented in Table 10.

TABLE 10—ANALYSIS OF VARIANCE OF COEFFICIENTS OF DIGESTIBILITY OF MANGELS WHEN ARRANGED BY RATIONS AND BY ANIMALS

For—n_1 = 3, n_2 = 24, then z is 0.5508 at 5% points, 0.7757 at 1%
n_1 = 8, n_2 = 24, then z is 0.4283 at 5% points, 0.6064 at 1%
n_1 = 24, n_2 = 8, then z is 0.5682 at 5% points, 0.8319 at 1%

Nutrient	Variance due to	F	Sums of squares	Variance	½ Log$_e$ variance*	z compared with erroı
Dry matter	Animal	3	43.28	14.43	1.3345	0.2042
	Ration	8	71.03	8.88	1.0918	0.0385
	Error	24	230.13	9.59	1.1303	
	Total	35	344.44			
Organic matter	Animal	3	63.18	21.06	1.5237	0.3229
	Ration	8	60.32	7.54	1.0101	0.1907
	Error	24	267.99	11.17	1.2008	
	Total	35	391.49			
Nitrogen	Animal	3	179.91	59.97	2.0469	0.2766
	Ration	8	537.53	67.19	2.1038	0.3335
	Error	24	827.65	34.49	1.7703	
	Total	35	1545.09			
N-free extract	Animal	3	24.73	8.24	1.0547	0.1603
	Ration	8	19.63	2.45	0.4489	0.4455
	Error	24	143.56	5.98	0.8944	
	Total	35	187.92			

* Data under "Sums of Squares" and "Variance" carried to four decimal places in making these calculations for dry matter and N-free extract.

The results for the calculated coefficients have been expressed graphically in Figure 1. In a graph of this type, constant digestibility is indicated by a straight line, and a decreasing digestibility by a curve concave downward.

In the statistical analysis, only four nutrients have been considered, namely, dry matter, organic matter, nitrogen and nitrogen-free extract. These should serve to characterize fully the trend of digestibility of the mangels. The ether extract is a negligible quantity in mangels and it is impossible to calculate its coefficients of digestibility. The coefficients of the crude fibre showed wide variations. This fact is illustrated in Figure 1. A statistical analysis did not, therefore, seem justified. As seen from the graph, however, a straight line seemed to express in the best manner the trend of the digestibility of this nutrient.

For the dry matter and organic matter, the coefficients of digestibility determined directly and calculated from rations I, III, IV and V can be considered identical. The values for rations II, VI and VII were slightly

lower than the others. Statistically, the differences between the means were not significant. It is possible, however, that at top levels there may be a slight lowering of the digestibility, perhaps to the order of 1%. Attention should be directed to the coefficients of variation for the individual means. At level I, these coefficients were rather high, but fell off rapidly

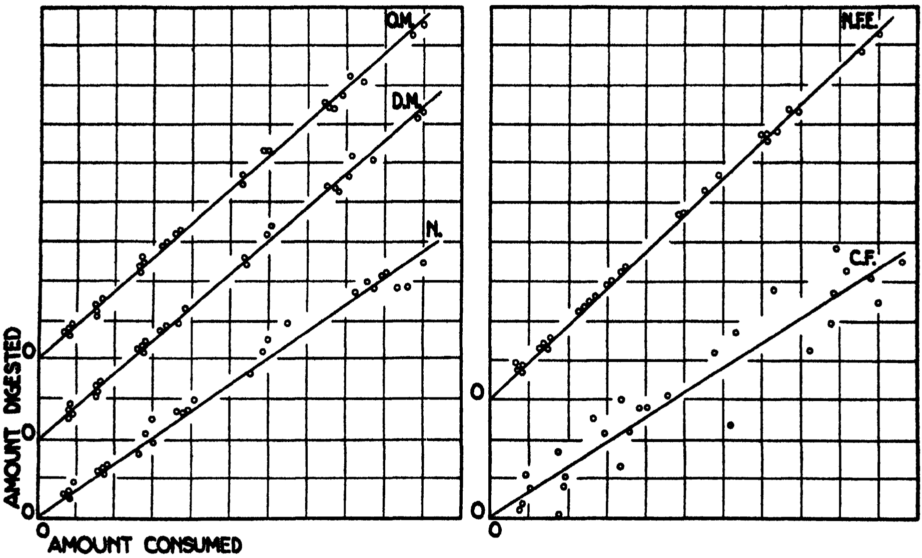

FIGURE 1.—Nutrients in mangels consumed. D.M. = Dry Matter; O.M. = Organic Matter; N. = Nitrogen; N.F.E. = Nitrogen-free Extract; C.F. = CrudeFibre; O. = Origin. The amount of nutrients consumed was calculated in kilograms and adjusted to a common scale for these graphs.

as the level of feeding increased. They were quite small for levels IV, V, VI and VII as well as for the mangels alone. The values for levels II and III were reasonably satisfactory. At level I, of course, when only 5 kilos of roots were fed with the four kilos of hay, the usual errors coincident with the calculation of coefficients of digestibility by difference were greatly magnified.

The means of the coefficients of digestibility of the nitrogen-free extract were remarkably uniform, though there was a slight lowering at the top levels. Statistically, the 36 values were homogenous thus substantiating the conclusions arrived at for the dry matter and the organic matter.

Considerable variation existed among the nitrogen values and in the case of rations I and III, the coefficients of variation were too large, being 14.89 and 14.63, respectively. At the top levels, the digestibility was somewhat lower, though not significantly so. However, more uniformity among the individual values would have greatly decreased the error with which the differences between periods were compared. Nevertheless, apart from the values at the top levels there was no evidence whatsoever that either the plane of feeding or the association with the hay affected the coefficients of digestibility.

It would seem, therefore, justifiable to consider the 36 values for the coefficients of digestibility of each of the three nutrients, dry matter,

organic matter and N-free extract, as homogeneous. Since they included values for mangels alone as well as for mixtures with a constant hay ration at all levels of feeding, then it follows that neither the plane of nutrition nor the association with hay affected the digestibility of the mangels. In the case of nitrogen, the possibility that there was a slight lowering of digestibility at the top levels cannot be excluded. For the remaining levels, however, the plane of nutrition had no effect. There was no associative effect.

SUMMARY

Digestion trials were conducted with four grade Shorthorn steers on the following rations: hay alone, mangels alone, and mixed rations of hay and mangels in which the hay was fed at a constant level of four kilogrammes per animal per day and the mangels at levels of 5, 10, 16, 22, 35, 50 and ad libitum kilogrammes per animal per day.

Neither the association with the hay nor the level of feeding significantly affected the digestibilities of the nutrients of the mangels.

The possibility cannot be excluded that at maximum levels of feedings the digestibility of the protein may be somewhat depressed.

Any possible depression of the digestibility of the dry matter, organic matter or nitrogen-free extract at maximum levels of feeding cannot be greater than 1 or 2%.

ACKNOWLEDGMENT

The authors wish to acknowledge the analytical assistance rendered by W. R. Inman and W. A. MacDougall.

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APPENDIX

Table 11.—Calculation of coefficients of digestibility
(Collection period of 12 days, weights in kilogrammes. Coefficients in per cent.)

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			Period 1				
Animal A							
Hay	48.000	41.227	38.139	0.770	0.771	15.839	16.713
Mangels	60.000	6.324	5.703	0.135	0.032	0.525	4.300
Total ration	108.000	47.551	43 842	0.905	0.803	16.364	21.013
Feces	104.061	20.465	18.441	0.367	0.467	9.103	6.729
Digested		27 086	25.401	0.538	0.336	7.261	14.284
Coefficient		57.0	57.9	59.4	41.8	44.4	68.0
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Dig. from mangels		5 566	5.187	0.095	0.007	0.609	4.039
Coeff. of mangels		88.0	91.0	70.4	21.9	116.0	93.9

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 1—*Concluded*				
Animal B							
Hay	48.000	41.227	38.139	0.770	0.771	15.839	16.713
Mangels	120.000	12.648	11.406	0.271	0.065	1.050	8.599
Total ration	168.000	53.875	49.545	1.041	0.836	16.889	25.312
Feces	107.470	21.462	19.063	0.399	0.483	9.666	6.621
Digested		32.413	30.482	0.642	0.353	7.223	18.691
Coefficient		60.2	61.5	61.7	42.2	42.8	73.8
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Dig. from mangels		10.893	10.268	0.199	0.024	0.571	8.446
Coeff. of mangels		86.1	90 0	73.4	36.9	54 4	98.2
Animal C							
Hay	48.000	41 227	38.139	0.770	0.771	15.839	16.713
Mangels	192.000	20.237	18.250	0.433	0 103	1 680	13 759
Total ration	240.000	61.464	56.389	1 203	0.874	17.519	30.472
Feces	127.063	22.307	19.927	0.433	0 509	9 648	7.241
Digested		39 157	36.462	0.770	0.365	7.871	23.231
Coefficient		63.7	64.7	64.0	41.8	44.9	76.2
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10 245
Dig. from mangels		17 637	16.248	0 327	0 036	1.219	12 986
Coeff. of mangels		87.2	89.0	75.5	35 0	72.6	94 4
Animal D							
Hay	48.000	41.227	38.139	0 770	0 771	15.839	16 713
Mangels	264 000	27.826	25.093	0.596	0 142	2.310	18.919
Total ration	312.000	69.053	63.232	1.366	0.913	18 149	35 632
Feces	143.863	23.764	21.181	0.506	0.577	9 917	7.664
Digested		45.289	42 051	0.860	0.336	8.232	27.968
Coefficient		65.6	66.5	63.0	36 8	45.4	78.5
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Fig. from mangels		23.769	21.837	0.417	0.007	1.580	17 723
Coeff. of mangels		85.4	87.0	70.0	4.9	68.4	93 7
			PERIOD 2				
*Animal A**							
Hay	64.000	55.187	50.595	1.155	1.049	20.149	22.180
Mangels	975.000	100.815	90.129	2.064	0.575	7.571	69.089
Total ration	1039.000	156.002	140.724	3.219	1.624	27 720	91.269
Feces	315.466	43.275	37.121	1.228	1.359	15.146	13.649
Digested		112.727	103.603	1.991	0.265	12.574	77.620
Coefficient		72.3	73.6	61.9	16.3	45.4	85.0
Dig. from hay		28.808	26.815	0.664	0.448	8.463	13.596
Dig. from mangels		83.919	76.788	1.327	—	4.111	64.024
Coeff. of mangels		83.2	85.2	64.3	—	54.3	92.7
Animal B							
Hay	90.000	77.607	71.150	1.624	1.475	28.334	31.190
Feces	182.882	37.205	33.503	0.672	0.956	16.061	12.579
Digested		40.402	37.647	0.952	0.519	12.273	18.611
Coefficient		52.1	52.9	58.6	35.2	43.3	59.7

* Collection period of 16 days.

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 2—*Concluded*				
Animal C							
Mangels	336.000	34.742	31.059	0.711	0.198	2.609	23.809
Feces	31.623	5.188	4.170	0.148	0.195	1.944	1.186
Digested		29.554	26 889	0.563	0.003	0.665	22.623
Coefficient		85.1	86.6	79.2	1 5	25.5	95.0
Animal D							
Hay	48.000	41.390	37.946	0 866	0.786	15.111	16.635
Mangels	60.000	6.204	5.546	0 127	0.035	0.466	4.252
Total ration	108.000	47.594	43.492	0 993	0.821	15.577	20.887
Feces	112.460	21.139	18.966	0 391	0.539	9.083	6.993
Digested		26.455	24.526	0.602	0.282	6.494	13.894
Coefficient		55 6	56.4	60 6	34.3	41.7	66.5
Dig. from hay		21 606	20 111	0.498	0.336	6.347	10.197
Dig. from mangels		4 849	4.415	0.104	—	0.147	3.697
Coeff. of mangels		78.2	79 6	81.9	—	31.5	86.9
			PERIOD 3				
Animal A							
Hay	48.000	41 477	38.051	0.817	0.771	15.226	16.948
Mangels	120.000	11.796	10.481	0.269	0.108	1.000	7.690
Total ration	168.000	53.273	48 532	1.086	0.879	16.226	24.638
Feces	118.654	21 684	19.164	0.445	0 536	8.903	7.060
Digested		31.589	29.368	0.641	0.343	7.323	17.578
Coefficient		59 3	60.5	59 0	39.0	45.1	71.3
Dig. from hay		21.651	20.167	0 470	0.329	6.395	10.389
Dig. from mangels		9 938	9 201	0.171	0.014	0.928	7.189
Coeff. of mangels		84.2	87.8	63.6	13 0	92.8	93.5
Animal B							
Hay	48.000	41.477	38.051	0.817	0.771	15.226	16.948
Mangels	600.000	58.980	52.404	1 346	0.543	5.002	38.449
Total ration	648.000	100 457	90.455	2.163	1.314	20.228	55.397
Feces	195.342	29.874	25.378	0.792	0.822	10.626	9.425
Digested		70.583	65.077	1.371	0.492	9.602	45.972
Coefficient		70.3	71.9	63.4	37.4	47.5	83.0
Dig. from hay		21.651	20.167	0.470	0.329	6.395	10.389
Dig. from mangels		48 932	44.910	0.901	0 163	3.207	35.583
Coeff. of mangels		83.0	85.7	66.9	30.0	64.1	92.5
Animal C							
Hay	48.000	41.477	38.051	0.817	0.771	15.226	16.948
Mangels	264.000	25.951	23.057	0.592	0.239	2.201	16.917
Total ration	312.000	67.428	61.108	1.409	1.010	17.427	33.865
Feces	136.169	23.633	20.719	0.521	0.574	9.453	7.633
Digested		43.795	40.389	0.888	0.436	7.974	26.232
Coefficient		65.0	66.1	63.0	43.2	45.8	77.5
Dig. from hay		21.651	20.167	0.470	0.329	6.395	10.389
Dig. from mangels		22.144	20.222	0.418	0.107	1.579	15.843
Coeff. of mangels		85.3	87.7	70.6	44.8	71.7	93.7

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 3—*Concluded*				
Animal D[1]							
Hay	64.000	55.302	50.734	1.089	1.029	20.301	22.596
Mangels	835.000	82.081	72.929	1.873	0.755	6.960	53.509
Total ration	899.000	137.383	123.663	2.962	1.784	27.261	76.105
Feces	269.395	39.695	34.221	1.068	1.076	14.032	12.825
Digested		97.688	89.442	1.894	0.708	13.229	63.280
Coefficient		71.1	72.3	63.9	39.7	48.5	83.1
Dig. from hay		28.868	26.889	0.626	0.439	8.526	13.851
Dig. from mangels		68.820	62.553	1.268	0.269	4.703	49.429
Coeff. of mangels		83.8	85.8	67.7	35.6	67.6	92.4
			PERIOD 4				
Animal A							
Hay	90.000	77.985	71.933	1.538	1.435	29.806	31.077
Feces	200.240	37.430	33.908	0.645	0.805	16.978	12.168
Digested		40.555	38 025	0.893	0.630	12.828	18.909
Coefficient		52 0	52.9	58.1	43.9	43.0	60.8
Animal B							
Mangels	480.000	47.088	42.078	1.038	0.447	4.125	31.017
Feces	42.948	6.278	4.754	0.256	0.294	1.659	1.289
Digested		40.810	37.324	0.782	0.153	2.466	29.728
Coefficient		86.7	88.7	75.3	34.2	59.8	95.8
Animal C							
Hay	48.000	41.592	38.364	0.820	0.765	15.896	16.574
Mangels	420.000	41.202	36.818	0.908	0.391	3.609	27.140
Total ration	468.000	82.794	75.182	1.728	1.156	19.505	43.714
Feces	165.660	25.369	22.315	0.605	0.710	10.168	7.869
Digested		57.425	52.867	1.123	0.446	9.337	35.845
Coefficient		69.4	70.3	65.0	38.6	47.9	82.0
Dig. from hay		21.711	20.333	0.472	0.327	6.676	10.160
Dig. from mangels		35.714	32.534	0.651	0.119	2.661	25.685
Coeff. of mangels		86.7	88.4	71.7	30.4	73.7	94.6
Animal D							
Hay	48.000	41.592	38.364	0.820	0.765	15.896	16.574
Mangels	120.000	11.772	10.519	0.259	0.112	1.031	7.754
Total ration	168.000	53.364	48.883	1.079	0.877	16.927	24.328
Feces	128.536	21.936	19.832	0.419	0.537	9.805	7.033
Digested		31.428	29.051	0.660	0.340	7.122	17.295
Coefficient		58.9	59.4	61.2	38.8	42.1	71.1
Dig. from hay		21.711	20.333	0.472	0.327	6.676	10.160
Dig. from mangels		9.717	8.718	0.188	0.013	0.446	7.135
Coeff. of mangels		82.5	82.9	72.6	11.6	43.3	92.0
			PERIOD 5				
Animal A							
Hay	48.000	41.750	38.494	0.820	0.743	15.928	16.696
Mangels	600.000	57.900	51.792	1.277	0.452	4.684	38.677
Total ration	648.000	99.650	90.286	2.097	1.195	20.612	55.373
Feces	185.709	28.594	25.051	0.743	0.824	11.455	8.681
Digested		71.056	65.235	1.354	0.371	9.157	46.692
Coefficient		71.3	72.3	64.6	31.0	44.4	84.3
Dig. from hay		21.794	20.402	0.472	0.317	6.690	10.235
Dig. from mangels		49.262	44.833	0.882	0.054	2.467	36.457
Coeff. of mangels		85.1	86.6	69.1	11.9	52.7	94.3

[1] Collection period of 16 days.

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-Free extract
			PERIOD 5—*Concluded*				
Animal B							
Hay	48.000	41.750	38.494	0.820	0.743	15.928	16.696
Mangels	264.000	25.476	22.788	0.562	0.199	2.061	17.018
Total ration	312.000	67.226	61.282	1.382	0.942	17.989	33.714
Feces	117.691	23.560	21.041	0.492	0.629	10.062	7.436
Digested		43.666	40.241	0.890	0.313	7.927	26.278
Coefficient		65.0	65.7	64.4	33.2	44.1	77.9
Dig. from hay		21.794	20.402	0.472	0.317	6.690	10.235
Dig. from mangels		21.872	19.839	0.418	—	1.237	16,043
Coeff. of mangels		85.9	87.1	74.4	—	60.0	94.3
Animal C							
Hay	48.000	41.750	38.494	0.820	0.743	15.928	16.696
Mangels	650.000	62.725	56.108	1.383	0.489	5.074	41.900
Total ration	698.000	104.475	94 602	2.203	1.232	21.002	58.596
Feces	181.472	27.116	24.009	0.782	0.822	10.459	8.531
Digested		77.359	70 593	1 421	0 410	10.543	50.065
Coefficient		74 0	74.6	64 5	33.3	50.2	85.4
Dig. from hay		21.794	20.402	0.472	0.317	6.690	10.235
Dig. from mangels		55.565	50.191	0.949	0.093	3.853	39.830
Coeff. of mangels		88.6	89.5	68.6	19.0	75.9	95.1
Animal D							
Hay	90.000	78.282	72.176	1.538	1.393	29.865	31.305
Feces	223.126	38 029	34.584	0.647	0.920	17.680	12.184
Digested		40.253	37.592	0 891	0.473	12.185	19.121
Coefficient		51.4	52.1	57.9	34.0	40.8	61.1
			PERIOD 6				
Animal A							
Mangels	480.000	46.992	42.189	1.059	0.320	4.041	31.212
Feces	42.184	6 092	5.164	0.248	0.356	1.702	1.707
Digested		40.900	37.025	0.811	—	2.339	29.505
Coefficient		87.0	87.8	76.6	—	57.9	94.5
Animal B							
Hay	48.000	42 398	39.078	0.819	0.729	16.120	17.112
Mangels	420.000	41.118	36.916	0.927	0.280	3.536	27.311
Total ration	468.000	83.516	75.994	1.746	1.009	19.656	44.423
Feces	153.655	26.764	24.248	0.576	0.768	11.562	8.540
Digested		56.752	51.746	1.170	0.241	8.094	35.883
Coefficient		68.0	68.1	67.0	23.9	41.2	80.8
Dig. from hay		22.132	20.711	0.471	0.311	6.770	10.490
Dig. from mangels		34.620	31.035	0.699	—	1.324	25.393
Coeff. of mangels		84.2	84.1	75.4	—	37.4	93.0
Animal C							
Hay	48.000	42.398	39.078	0.819	0.729	16.120	17.112
Mangels	120.000	11.748	10.547	0.265	0.080	1.010	7.803
Total ration	168.000	54.146	49.625	1.084	0.809	17.130	24.915
Feces	124.121	22.886	20.689	0.416	0.570	10.324	7.216
Digested		31.260	28.936	0.668	0.239	6.806	17.699
Coefficient		57.7	58.3	61.6	29.5	39.7	71.0
Dig. from hay		22.132	20.711	0.471	0.311	6.770	10.490
Dig. from mangels		9.128	8.225	0.197	—	0.036	7.209
Coeff. of mangels		77.7	78.0	74.3	—	3.6	92.4

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 6—*Concluded*				
Animal D							
Hay	48.000	42.398	39.078	0.819	0.729	16.120	17.112
Mangels	600.000	58.740	52.737	1.324	0.399	5.052	39.015
Total ration	648.000	101.138	91.815	2.143	1.128	21.172	56.127
Feces	203.876	29.439	26.336	0.751	0.992	11.596	9.447
Digested		71.699	65.479	1.392	0.136	9.576	46.680
Coefficient		70.9	71.3	65.0	12.1	45.2	83.2
Dig. from hay		22.132	20.711	0 471	0.311	6 770	10.490
Dig. from mangels		49.567	44.768	0.921	—	2.806	36.190
Coeff. of mangels		84.4	84 9	69.6	—	55.5	92.8
			PERIOD 7				
Animal C							
Hay	90.000	80.046	73.554	1 622	1 441	28.753	33.219
Feces	198.832	38.287	34.573	0.712	0.953	17.329	12.145
Digested		41.759	38.981	0.910	0.488	11.424	21.074
Coefficient		52.2	53 0	56.1	33.9	39.7	63.4
			PERIOD 8				
Animal A							
Hay	90.000	79.767	73.362	1.609	1.787	29.785	31.739
Feces	193.066	37.892	34 148	0 666	0.913	17 237	12.114
Digested		41.875	39.214	0.943	0.874	12.548	19.625
Coefficient		52 5	53.5	58.6	48 9	42 1	61.8
Animal B							
Hay	48.000	42 542	39.126	0.858	0.953	15.885	16.927
Mangels	192.000	21.331	18.778	0.463	0 111	1 928	13 844
Total ration	240.000	63.873	57 904	1.321	1 064	17.813	30.771
Feces	106.681	22.442	19.801	0 441	0 626	9.430	7.206
Digested		41.431	38 103	0.880	0.438	8.383	23.565
Coefficient		64.9	65 8	66.6	41.2	47.1	76 6
Dig. from hay		22.207	20 737	0 493	0.407	6.672	10.376
Dig. from mangels		19.224	17 366	0 387	0.031	1.711	13.189
Coeff. of mangels		90 1	92.5	83.6	27.9	88.7	95.3
Animal C							
Hay	48.000	42.542	39.126	0 858	0.953	15.885	16.927
Mangels	600.000	66.660	58 681	1.447	0.347	6.026	43.262
Total ration	648.000	109.202	97.807	2.305	1.300	21.911	60.189
Feces	212.385	32.367	27.664	0.912	0.948	11.536	10.053
Digested		76.835	70.143	1.393	0.352	10.375	50.136
Coefficient		70.4	71.7	60.4	27.1	47.4	83.3
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		54.628	49.406	0.900	—	3.703	39.760
Coeff. of mangels		82.0	84.2	62.2	—	61 5	91.9
Animal D							
Mangels	480.000	53.328	46.945	1.158	0.277	4.821	34.610
Feces	40.446	6.945	5.183	0.250	0.373	1.847	1.620
Digested		46.383	41.762	0.908	—	2.974	32.990
Coefficient		87.0	89.0	78.4	—	61.7	95.3

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 9				
Animal A							
Hay	48.000	42.542	39.126	0.858	0.953	15.885	16.927
Mangels	264.000	29.304	25.603	0.632	0.144	2.620	18.892
Total ration	312.000	71.846	64.729	1.490	1.097	18.505	35.819
Feces	125.873	23.866	21.021	0.535	0.616	10.076	7.262
Digested		47.980	43.708	0.955	0.481	8.429	28.557
Coefficient		66.8	67.5	64.1	43.8	45.5	79.7
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		25.773	22.971	0.462	0.074	1.757	18.181
Coeff. of mangels		88.0	89.7	73.1	51.4	67.0	96.2
Animal B							
Hay	90 000	79 767	73.362	1.609	1.787	29.785	31.739
Feces	186.192	37.711	34.162	0.647	0 879	17.019	12.486
Digested		42 056	39.200	0.962	0.908	12.766	19.253
Coefficient		52.7	53 4	59.8	50.8	42.9	60.7
Animal C							
Mangels	480 000	53.280	46.551	1.148	0.261	4.763	34.350
Feces	52.807	8.515	6.729	0.310	0.399	2.540	2.076
Digested		44 765	39.822	0.838	—	2.223	32.274
Coefficient		84 0	85.5	73.0	—	46.7	94.0
Animal D							
Hay	48.000	42.542	39.126	0.858	0.953	15.885	16 927
Mangels	420.000	46.620	40.732	1.005	0.228	4 168	30.056
Total ration	468.000	89.162	79.858	1.863	1 181	20 053	46.983
Feces	161.771	25 119	21.994	0 604	0 691	10.115	7.794
Digested		64 043	57.864	1.259	0.490	9.938	39.189
Coefficient		71.8	72.5	67 6	41 5	49.6	83.4
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		41 836	37.127	0.766	0 083	3.266	28.813
Coeff. of mangels		89.7	91.1	76.2	36.4	78.4	95.9
			PERIOD 10				
Animal A							
Mangels	480.000	52 080	46 028	1 160	0.271	4.781	33.727
Feces	46.768	6.702	5.387	0.311	0.412	1.669	1.578
Digested		45.378	40.641	0.849	—	3.112	32.149
Coefficient		87.1	88.3	73.2	—	65.1	95.3
Animal B							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	60.000	6.510	5.754	0.145	0.034	0.598	4.216
Total ration	108.000	48.611	44.584	0.986	0.956	16.171	21.296
Feces	84.949	20.463	18.470	0.368	0.520	9.210	6.509
Digested		28.148	26.114	0.618	0.436	6.961	14.787
Coefficient		57.9	58.6	62.7	45.6	43.0	69.4
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		6.171	5.534	0.134	0.042	0.420	4.317
Coeff. of mangels		94.8	96.2	92.4	—	70.2	102.4

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 10—*Concluded*				
Animal C							
Hay	90.000	78.939	72.805	1.576	1.729	29.200	32.026
Refused hay	3.646	3.184	2.935	0.058	0.057	1.243	1.271
Consumed	86.354	75.755	69.870	1.518	1.672	27.957	30.755
Feces	196.788	35.635	32.460	0.683	0.827	16.157	11.517
Digested		40.120	37.410	0.835	0.845	11.800	19.238
Coefficient		53.0	53.5	55.0	50.5	42.2	62.6
Animal D							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	192.000	20.832	18.411	0.464	0.108	1.912	13.491
Total ration	240.000	62.933	•57.241	1.305	1.030	17.485	30.571
Feces	140.040	23.648	21.080	0 526	0.608	10.211	7.255
Digested		39.285	36.161	0.779	0.422	7.274	23.316
Coefficient		62.4	63.2	59.7	41.0	41.6	76.3
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		17.308	15.581	0.295	0.028	0 733	12.846
Coeff. of mangels		83.1	84.6	63.6	25.9	38 3	95.2
			PERIOD 11				
Animal A							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	192.000	21.024	19 094	0.407	0.107	1.528	14.914
Total ration	240.000	63.125	57.924	1.248	1.029	17.101	31.994
Feces	119.297	23.238	20 656	0.513	0.892	9 109	7.615
Digested		39.887	37 268	0.735	0.137	7 992	24.379
Coefficient		63.2	64 3	58 9	13.3	46.7	76.2
Dig. from hay		21.977	20.580	0 484	0.394	6.541	10.470
Dig. from mangels		17.910	16 688	0.251	—	1.451	13.909
Coeff. of mangels		85.2	87.4	61.7	—	95.0	93.3
Animal B							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	700.000	76.650	69.614	1.484	0 391	5.572	54.376
Total ration	748.000	118.751	108.444	2.325	1.313	21.145	71.456
Feces	225.398	32.963	28.276	0.939	1.048	11.188	10.736
Digested		85.788	80.168	1.386	0.265	9.957	60.720
Coefficient		72.2	73.9	59.6	20.2	47.1	85.0
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		63.811	59.588	0.902	—	3.416	50.250
Coeff. of mangels		83.2	85.6	60.8	—	61.3	92.4
Animal C							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	60.000	6.570	5.967	0.127	0.034	0.478	4.661
Total ration	108.000	48.671	44.797	0.968	0.956	16.051	21.741
Feces	98.189	21.249	19.096	0.399	0.574	9.333	6.838
Digested		27.422	25.701	0.569	0.382	6.718	14.903
Coefficient		56.3	57.4	58.8	40.0	41.9	68.5
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		5.445	5.121	0.085	—	0.177	4.433
Coeff. of mangels		82.9	85.8	66.9	—	37.0	95.1

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Concluded*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Concluded*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-Free extract
			PERIOD 11—*Concluded*				
Animal D							
Hay	90.000	78.939	72.805	1.576	1 729	29.200	32.026
Feces	206.341	38.157	34.551	0.701	0.962	16.930	12.603
Digested		40.782	38.254	0.875	0.767	12.270	19.423
Coefficient		51.7	52.5	55.5	44.4	42.0	60.6
			PERIOD 12				
Animal A							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	420.000	45.444	41.204	0.868	0.427	3.304	32.043
Total ration	468.000	87.545	80.034	1.709	1.349	18.877	49.123
Feces	151.351	25.746	22.358	0.658	0.832	9.971	7.927
Digested		61.799	57.676	1.051	0.517	8.906	41.196
Coefficient		70.6	72.1	61.5	38.3	47.2	83.9
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		39.822	37.096	0.567	0.123	2.365	30.726
Coeff. of mangels		87.6	90.0	65.3	28.8	71.6	95.9
Animal B							
Mangels	480.000	51.936	47.090	0.992	0.488	3.776	36.620
Feces	45.946	6.616	5.011	0.276	0.419	1.424	1.636
Digested		45.320	42.079	0.716	0.069	2.352	34.984
Coefficient		87.3	89.4	72.2	14.1	62.3	95.5
Animal D							
Mangels	480.000	51.936	47.090	0.992	0.488	3.776	36.620
Feces	60.199	8.132	6.322	0.340	0.413	1.936	2.114
Digested		43.804	40.768	0.652	0.075	1.840	34.506
Coefficient		84.3	86.6	65.7	15.4	48.7	94.2

PASTURE STUDIES XIII

THE UTILIZATION OF NATIVE AND APPLIED PHOSPHORUS BY PASTURE CROPS[1]

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[Received for publication March 1, 1938]

INTRODUCTORY STATEMENT

The fertilizer trial plots of the Macdonald College pasture committee were located in the Eastern Townships of Quebec, in the neighbourhood of the town of Cowansville, throughout the seasons of 1931 to 1934 inclusive. The normal soil in this district is of the type described by McKibbin and Pugsley (6) as brown forest soil. A rough reconnaissance survey has indicated that soils of this type are mainly restricted to a narrow zone lying between the alluvial soils of the St. Lawrence valley and the upland podsol soils of the Appalachian region. Raymond (10) presented a sketch map showing the result of this survey.

The brown forest soils have not been intensively studied, but it may be stated that they are not as drastically leached as are the podsol soils, which are so important from the standpoint of area in Quebec province. In the virgin brown forest soil profile there is little tendency for peaty organic matter to accumulate at the surface, and well decomposed organic matter is distributed through the profile to considerable depth, decreasing gradually from the surface downward. Sesquioxides do not appear to have been translocated to any marked extent. The profile is devoid of any sharp division into layers, and there is no notable development of structure. These soils are distinctly acid, having a pH range of 5.0 to 6.0; they are in general not as acid as the upland podsol soils, and their lime requirement is lower. Genetically, these soils appear to have developed from parent material richer in basic elements than that which underlies the upland podsols, and under a forest cover that was made up mainly of deciduous species. Agriculturally they are somewhat superior to the podsols.

Several publications of the Macdonald College pasture committee deal with the various effects of top-dressing permanent pastures on the brown forest soil type with different fertilizers and amendments. Nowasad (8) reported the effects of fertilization on botanical composition and yield. Crampton and Finlayson (2) showed that the nutritive value of herbage clipped from fertilized areas was greater than that from the natural pasture. Dore (3) presented a detailed analysis of the succession and variation in botanical composition resulting from fertilizer application. The unpublished work of Stobbe (11) records the influence of fertilizer treatments on the contents of nitrogen, calcium, and phosphorus in the clipped herbage. All these workers have concluded that phosphorus, applied to the surface as superphosphate, is outstanding in producing beneficial results.

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[1] Contribution from the Macdonald College Pasture Committee, Professor L. C. Raymond, Chairman. Macdonald College Journal Series No. 97. Constructed from a Ph.D. thesis presented to McGill University by C. L. Wrenshall.

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This paper presents results obtained in a chemical study of the soil phosphorus conditions in field and greenhouse experiments, and traces the relation of these conditions to observed plant response. This work has already been cited by Raymond (10), and an abstract which summarized the results appeared in this journal (13). In view of their value in explaining the action of phosphorus in pasture fertilization, and as a contribution to the general study of soil phosphorus relationships, the data appear worthy of more detailed presentation.

A. PHOSPHORUS CONDITIONS IN THE SOIL OF THE PASTURE PLOTS

Experimental Material and Method

A total of 126 soil samples was obtained from the fertilizer trial plots. Various treatments had been laid down on several farms in each of four successive years. The sampling was done in September, 1934, so that the samples represented conditions existing at four different intervals of time after the addition of fertilizer. The treatments sampled were nil, superphosphate, and superphosphate plus muriate of potash; various rates of application were represented. The treatments had been applied as top-dressings broadcast on the surface of the pastures, with no attempt to work in the applications. Three samples, representing the soil layers (i) 0″ to ½″, (ii) ½″ to 1½″, (iii) 1½″ to 3″, were obtained from each plot studied.

The samples were air-dried, pulverized with a rubber pestle, and screened through a sieve of 20 meshes to the inch. All samples were analyzed for readily soluble phosphorus using the Quebec extraction method[4], the development of which was described in a previous publication (14). A few total-phosphorus determinations were made, using the standard A.O.A.C. magnesium nitrate fusion method.

Data and Discussion

Results of the analyses for readily soluble inorganic phosphorus are recorded in Table 1. Several points of considerable interest are revealed by these data.

Considering untreated soils, the soluble phosphorus is seen to be higher in the topmost one-half inch than in the succeeding layers. This is true in each case represented. Analyses for total phosphorus in samples from the 1934 series on farm No. 1 are presented in Table 2, and show a similar relationship for the distribution of total phosphorus. This situation is noteworthy, as it indicates that the plants act as pumps, bringing up some phosphorus from the lower soil layers, and, in returning to the soil, adding it to the upper layers where it is closely retained, a small portion in readily soluble inorganic form.

Surface application of superphosphate has resulted in an increase in the readily soluble phosphorus of the surface half-inch layer of soil. This is best observed in the data for the 1933 and 1934 treatments, where the

[4] The Quebec extracting solution contains 500 parts per million of calcium (Ca) and 1,270 parts per million of sulphate (SO_4), and has a reaction value of pH 3 0. It is prepared by dissolving 1 25 grams of pure calcium carbonate in the equivalent of 265 cc of tenth-normal sulphuric acid for each litre of final solution. Two grams of soil are extracted with 400 cc. of Quebec solution for half an hour in an end-over-end shaker; filtration is immediately carried out, using high grade filter paper and suction, and phosphorus in the extract is determined colorimetrically following the Truog and Meyer (12) technique.

effect is sufficiently recent to be quite marked. The most pronounced result, together with total phosphorus data, is quoted in Table 2. It appears that all the phosphorus of the application has been retained by the surface half-inch layer, and the data throughout indicate that the effect of phosphorus additions has been confined to this thin stratum. Such a result betokens the great power of these soils to fix phosphate, and indicates that the reaction between soil and dissolved phosphate must be practically instantaneous.

The great power of most soils to fix additions of soluble phosphate is well known and has been noted by many authors. Evidently Quebec soils present no exception to the general rule. Midgley (7), in studies relative to phosphate fertilization of permanent pastures in Wisconsin, observed that a three-quarter inch layer of soil on a Buchner funnel completely retained the phosphorus of experimental applications of superphosphate. Brown and Munsell (1) found that superphosphate was almost altogether fixed in the surface inch of top-dressed pasture soil. It is believed, however, that these results are the first to demonstrate clearly that the effect of top-dressing with superphosphate may be entirely confined to the surface one-half inch of soil under field conditions.

It would be of interest in this connection to know what influence this lack of penetration of the applied phosphorus has upon its availability to plants. That it is available to a considerable extent is obvious from the practical results. Would the application be more effective if it were mingled with the soil to a greater depth? Would the effect on botanical composition be the same? Unfortunately we cannot as yet give direct answers to these questions. Midgley (7) found that the yield increase of blue-grass was much greater when the treatment was incorporated to a depth of three inches. On the other hand, practical instances in which top-dressing was superior to incorporation are known (5). Goedewaagen (4) showed a given amount of applied phosphorus to be more effective when mingled with only the surface zone than when incorporated throughout the soil of the culture. It is to be kept in mind that only a portion of the total phosphorus applied remains in a readily soluble condition (see Table 2). the remainder being fixed in relatively insoluble forms. With a greater ratio of soil to phosphorus, such as would occur if the treatment were worked in, a greater proportion might be fixed in difficultly soluble form. Probably there is an optimum condition between the extremes of positional unavailability and excessive dilution of the applied phosphate.

From Dore's results (3), it is evident that the grass species do not make a strong response to the applied phosphate in the first season after treatment, while white clover increases very markedly. Dore's comments on this point are instructive. By its habit of growth, white clover appears to be peculiarly adapted for obtaining nutrients in the uppermost part of the soil. The stolons of this species lie close to the surface of the ground and send down slender, white feeding roots directly into the topsoil. The grasses appear to have relatively few feeding roots in the surface half-inch layer, and, although they may be capable of responding to phosphate to as great an extent as is clover[5], such response is delayed and curtailed by the small ability of their root systems to come into contact with the supply.

[5] Cf. response of timothy and clover in the pot-culture experiment.

TABLE 1.—READILY SOLUBLE INORGANIC PHOSPHORUS IN SOIL. SAMPLES FROM THE PASTURE PLOTS AT SEPTEMBER, 1934

Year of fertilization	Soil from farm No.	Top dressing*	Parts per million of inorganic phosphorus dissolved by Quebec extraction — From soil horizon		
			0" - ½"	½" - 1½"	1½" - 3"
1931	I	Nil	12	4	3
		5P	24	6	4
		5P, 1.6K	12	6	4
	II	Nil	9	5	4
		5P	13	5	3
		5P, 1.6K	10	5	4
1932	III	Nil	6	4	4
		5P	12	4	4
		5P, 1.6K	6	3	3
	I	Nil	12	7	5
		3P, 1.5K	13	7	6
		5P, 1.5K	15	7	6
		7P, 1 5K	17	7	5
	II	Nil	10	4	3
		3P, 1.5K	11	5	4
		5P, 1 5K	12	4	3
		7P, 1.5K	11	5	4
1933	I	Nil	10	5	3
		5P	23	5	4
		5P, 1 6K	30	9	6
	III	Nil	10	4	4
		5P	33	5	4
		5P, 1.6K	25	5	4
	IV	Nil	9	4	3
		5P	19	5	4
		5P, 1 6K	17	5	4
	II	Nil	12	5	4
		5P	47	8	4
		5P, 1.5K	26	5	3
1934	I	Nil	12	8	7
		7P	80	8	7
		7P, 2K	55	10	7
	III	Nil	9	5	4
		7P	53	5	4
		7P, 2K	33	7	4
	IV	Nil	7	3	2
		3P	12	3	3
		5P	24	4	3
		7P	34	3	2
		3P, 2K	22	3	2
		5P, 2K	40	5	4
		7P, 2K	35	3	3

* Fertilizer applications are designated in abbreviated form: P = superphosphate, K = muriate of potash; the numbers indicate the rate of application in hundreds of pounds per acre. Thus 5P = 500 lbs. of superphosphate per acre; 5P, 1.6K = 500 lbs. of superphosphate + 160 lbs. of muriate of potash per acre.

TABLE 2.—DISTRIBUTION OF PHOSPHORUS IN PASTURE SOIL FROM FARM I, 1934 SERIES

Depth of soil layer (inches)	Parts per million of phosphorus in soil			
	Unfertilized		Fertilized (7P)	
	Total	Readily soluble	Total	Readily soluble
0 - ½	1000	12	1200	80
½ - 1½	850	8	880	8
1½ - 3	700	7	700	7

Thus the concentration of added phosphate in a thin surface layer is undoubtedly a factor of paramount importance in determining the observed differential response of the sward species.

Where muriate of potash was added together with superphosphate in the original treatment, the amount of readily soluble phosphorus remaining in the soil at the time of sampling was generally lower than where superphosphate was added alone. This is true in 8 out of 13 comparable pairs. In these 13 cases the average soluble phosphorus in the surface of plots treated with phosphate alone was 31 parts per million, and the average for plots treated with both phosphate and potash was 26 parts per million. Furthermore, the values for farms I and II treated in 1932, where all treatments were of both elements and no direct comparison with phosphorus alone is possible, appear relatively low.

Generally, application of potash results in a significant yield increase, as shown by Nowosad (8). Thus the observed effect of potash on the soluble phosphorus status is attributable to increased consumption of phosphorus by the growing plants. It may also be due to increased reversion to difficultly soluble form, as appears to be the case in the pot culture experiment described in a later section.

The amount of easily soluble phosphorus remaining in the soil appears to diminish in a regular manner as the time since the application of fertilizer increases. This is to be expected if the plants are feeding on this particular fraction of the soil phosphorus. It might also be occasioned by a slow reversion to less soluble forms. Average values calculated for intervals of one crop season are presented in Table 3. Each average is calculated from all the values from plots which were fertilized in a given year, and the average of the nil plots is obtained from all available figures. The only average which is seriously out of line with the general trend is that for the

TABLE 3.—DEPLETION OF READILY SOLUBLE PHOSPHORUS AS RELATED TO BOTANICAL COMPOSITION AND YIELD

Number of crops removed since fertilization	Average soluble phosphorus—p.p.m. surface soil	Per cent ground covered by clover (Dore)	Per cent yield increase over untreated
1	39	40.2	51.4
2	27	30.5	34.0
3	12	18.3	18.3
4	15	14.8	–
Not fertilized	10	11.1	0.0

plots fertilized in 1932. In this case 7 of the 8 values included in the average are for plots treated with phosphate plus potash. If the observation made above concerning the effect of potash is sound, this average would be expected to be abnormally low, as it is.

It is well known that in the first season after fertilization the clover population of the sward is greatly increased and then suffers a gradual decline in the subsequent seasons. Dore (3) has presented such results obtained from the study of a series of plots through four successive seasons, and the several other series of plots have all shown similar trends, so that his data may be considered representative. The third column of Table 3 is calculated from Dore's data. The clover on untreated plots is the average for the four years; the other figures are average values for P and PK plots in each of the four years after fertilization. The close correspondence between the soluble phosphorus figures and those for ground covered by clover, expressed as they are in unrelated units, is doubtless fortuitous, but the high degree of correlation between these figures is unmistakable. It appears that the proportion of clover in the sward is very directly related to the amount of easily soluble phosphorus present in the top layer at the same time. That this is the case was strongly confirmed by refertilization experiments in which the treatment of plots originally fertilized in 1931 was repeated in the spring of 1935. On the P and PK treatments the clover responded strongly, just as it did after the original dressings. This occurred in spite of the fact that there was a closer sward of useful grass species at the time of the second application than at the first. This would seem to indicate that the proportion of white clover in the sward was directly conditioned by the amount of soluble phosphate; it increased sharply when the soluble phosphate was increased, decreased gradually as the phosphate slowly disappeared, and once more increased sharply when the soluble phosphate was suddenly replenished. There is very little support in this for the contention of Dore (3) that "The white clover declines, or better, is forced to decline due to the demands exerted on its territory by the slower growing, but stronger growing, grasses." Perhaps it would be better to state that the power of clover to compete depends directly on the supply of phosphorus available to it.

The fourth column of Table 3 shows data for the average percentage yield increase on P and PK plots in the years following fertilization. These figures are for the plots treated in 1933, and are known to be representative of the general behavior. Again, there is evident a direct relationship between the degree of yield response and the amount of soluble phosphate remaining in the soil.

B. THE POT CULTURE EXPERIMENT

A pot culture experiment was conducted in the greenhouse with a view to the further testing, under controlled conditions, of the soil and plant phosphorus relationships, and the extent to which these can be traced by soil analysis. Brown forest soil from a pasture in the Cowansville district was used, and the plants grown were timothy and wild white clover. Pasture conditions were imitated, in that the treatments applied were confined to the surface two-inch layer of soil, and that the plants were kept in the vegetative state by clipping at intervals. The experiment was

designed to avoid uncontrollable variation in material (soil and plants) and to be suitable for statistical analysis. The following treatments, each replicated three times with timothy and three times with clover, were tested:

	Treatment	*Abbreviation*
1.	Nil	Nil
2.	300 lbs. superphosphate (P) per acre	3P
3.	700 lbs. P per acre	7P
4.	1 ton limestone (L) per acre	L
5.	1 ton L + 300 lbs. P per acre	L, 3P
6.	1 ton L + 700 lbs. P per acre	L, 7P
7.	150 lbs. sulphur (S) per acre	S
8.	150 lbs. S + 300 lbs. P per acre	S, 3P
9.	150 lbs. S + 700 lbs. P per acre	S, 7P
10.	100 lbs. muriate of potash (K) per acre	K
11.	100 lbs. K + 300 lbs. P per acre	K, 3P
12.	100 lbs. K + 700 lbs. P per acre	K, 7P

Three clippings of clover and four of timothy were made in the course of the experiment. Each clipped sample was retained separately, oven dried, and weighed for yield of dry matter. Phosphorus was determined in each separate clipped sample by applying the colorimetric method of Truog and Meyer (12) to solutions of the plant ash. The data for yield and for phosphorus removal were subjected to statistical analysis of variance.

Soil samples representing the treated layer of soil were taken from the individual pots at the beginning and at the end of the experiment, and were analyzed for readily soluble phosphorus by the Quebec extraction method. Determinations of pH values were made on composites of the soil samples from each treatment.

Data and Discussion

The complete data from the experiment are too extensive and cumbersome to be reproduced here. The following is a summary of the information obtained by statistical examination of the results:

1. The yield of herbage and the phosphorus removed in the clipped herbage were significantly increased by phosphate fertilization at both rates, and the increases on the 7P treatments were significantly greater than those on the 3P treatments.

2. Application of lime caused a significant depression of both yield and phosphorus uptake in the case of timothy, but not in the case of clover. The effect of lime on clover was apparently parallel to that on timothy, but just failed to reach the 5% point of statistical significance.

3. Treatment with sulphur caused significant increases in both yield and phosphorus uptake of both species.

4. Treatment with potassium was without apparent effect on the growth of the plants.

5. There was no significant interaction between phosphate fertilization and the other treatments.

Tables 4 and 5 are designed to reveal the statistically significant differences in yield and phosphorus removal. The data in Table 4, showing effects of the treatments on total yield, are also given expression in Figure 1. The increases due to phosphate addition at two different rates are apparent; so also are the decreases due to lime, and the increases due to sulphur.

The depressions of yield and phosphorus removal caused by lime, and the increases due to sulphur tend to be uniform, and therefore are not related to the phosphate application, but are direct effects on the soil.

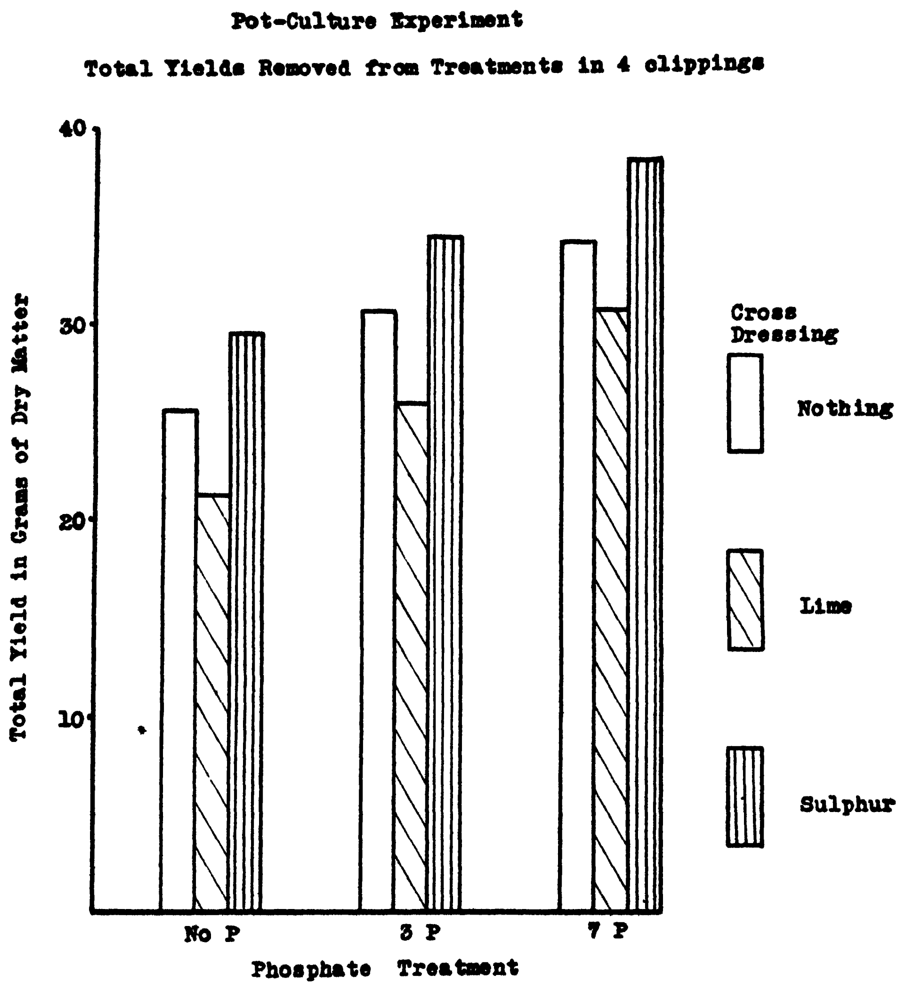

FIGURE 1

The nature of these effects is at present uncertain. We have previously shown (14) that the solubility of soil phosphate is depressed by the presence of calcium in the acid extracting solution, and postulated that a similar effect is operative in the soil. Thus an increase in calcium saturation of the soil, produced by liming, might be expected to reduce the solubility

of phosphate, and a decrease in calcium saturation, brought about by the oxidation of sulphur to sulphuric acid, should increase phosphate solubility. Pierre and Browning (9) obtained striking results showing bad effects from liming, and traced these effects to a decrease in the solubility of soil phosphate. That these factors are in operation here would seem to offer a plausible explanation of the observed results, except that there is no inter-action between the phosphate treatments and the cross-treatments of sulphur and lime, such as would be predicted on the basis of the assumption. The action of sulphur and lime may be due to other effects not directly related to the phosphorus nutrition of the plants.

TABLE 4.—TOTAL YIELDS OF DRY MATTER CLIPPED FROM DIFFERENT TREATMENTS (GRAMS)

Phosphatic treatments	Cross dressings		
	None	Lime	Sulphur
None	25.7	21.5	29.8
3P	30.6	26.1	34.6
7P	34.1	30.9	38.5

The results of this pot culture experiment with respect to sulphur and lime appear to be somewhat at variance with general agricultural belief, and the application of sulphur to acid soils is hardly to be recommended on such evidence. It is to be kept in mind that the result obtained is for one season's growth on a single sample of soil, and with plant species which appear to be well adapted to acid conditions. On the other hand, the pasture experimentation on this soil type has failed to show any clear-cut beneficial effect of lime applied as a surface dressing. In some cases slight yield increases have been recorded, but in other instances slight yield depressions. Likewise, in the case of potash, the absence of a significant yield response in this instance is not surprising; potash is often, but not always, beneficial. The degree of response to phosphate in the pot tests is of the same order as that observed in field trials. Altogether, the results are in accord with field observations.

TABLE 5.—PHOSPHORUS REMOVED IN THE CLIPPINGS FROM DIFFERENT TREATMENTS (MILLIGRAMS)

Phosphatic treatments	Cross dressings		
	None	Lime	Sulphur
None	76.9	68.7	95.8
3P	94 6	85.3	111.2
7P	122.1	103.0	133.2

The data for chemical determinations made on soil samples from the pots are recorded in Table 6. From the pH values it is evident that the addition of calcium carbonate has had an appreciable effect, increasing the pH values by approximately one unit. The addition of sulphur has not produced a marked effect, but the values are evidently reduced by 0.1 to 0.2 units. The treatments with superphosphate and muriate of potash have not caused any consistent effect on the soil reaction. The data for soluble phosphorus before growth show that the phosphate treatments have resulted in marked increases, while the other treatments have been without apparent effect. The increases in soluble soil phosphorus caused by phosphate application are evidently related to the increases in yield and phosphorus removal. The figures for available phosphate after growth

are, in general, lower than those obtained initially, indicating that some of this phosphorus has been removed or converted into less soluble forms.

TABLE 6.—CHEMICAL DATA ON SOIL FROM THE POTS

Treatment	Time of sampling relative to growth	Soluble phosphorus—p.p.m. of soil						pH of soil
		Replications						
		Clover			Timothy			
		1	2	3	4	5	6	
Nil	Before After	7 *	6	6	7 6	7 6	7 7	5.60
3P	Before After	18	19	17	16 10	18 11	19 14	5.58
7P	Before After	23	25	22	27 17	25 15	34 21	5.57
L	Before After	7	7	7	7 9	7 8	7 8	6.62
L, 3P	Before After	15	18	16	16 13	18 16	18 14	6.62
L, 7P	Before After	33	25	32	28 20	30 16	32 18	6.75
S	Before After	7	7	7	7 4	7 3	7 4	5.35
S, 3P	Before After	15	13	14	16 9	14 5	16 8	5.43
S, 7P	Before After	25	28	24	29 16	24 13	29 16	5.49
K	Before After	6	7	7	7 2	7 2	8 3	5 51
K, 3P	Before After	13	15	17	18 10	15 9	15 8	5.56
K, 7P	Before After	30	32	32	30 18	31 13	31 16	5.55

* Unfortunately, through not properly anticipating the value of these results, soil samples were not taken from the pots bearing clover at the conclusion of the growth period.

Several samples of the untreated subsurface soil were examined before and after the growth of plants. In no case was there a detectable decrease in the readily soluble phosphate of the lower, untreated layers. Hence we may confine our attention to the changes in phosphate status occurring in the treated zone. When the amount of soil involved in the change is known, the data of Table 6 permit the calculation of the apparent amount of soluble phosphorus that has passed from the soil to the timothy plants, assuming that the entire decrease is due to removal by the crop. This has been done, and the results are shown in Table 7, where they are compared with the actual amounts of phosphorus that were removed in the clippings.

The data of Table 7 are of considerable interest and significance. The phosphorus removed by growing plants is in all cases considerably more than is indicated by the disappearance of soluble phosphate. Evidently the soil is supplying the plants with phosphorus in a manner that is not detected by the acid extraction method. In the case of untreated soil the change in soluble phosphate is insignificant while the plants have obtained 44.3 milligrams of phosphorus. On the lime treatment the soluble phosphate appears to have increased slightly, while the amount obtained by the plants decreased to 35.7 milligrams. Where sulphur was applied the soluble phosphorus decreased sufficiently to account for the extra phosphorus obtained by the plants on this treatment, but the bulk of the phosphorus taken up is not accounted for. The result with potassium is anomalous, for the soluble phosphorus has decreased considerably without a corresponding increase in the amount taken up by the plants. In no case has the decrease in acid extractable[6] phosphorus accounted for the total phosphorus uptake by the crop, even though it may be safely assumed that part of the decrease was due to reversion to less soluble forms.

TABLE 7.—COMPARISON OF PHOSPHORUS REMOVAL FROM SOIL AS SHOWN BY CHEMICAL TESTS ON THE SOIL AND BY ANALYSIS OF TIMOTHY CLIPPINGS

Treatment	Apparent P removal shown by soil tests	Actual P removal in clipped timothy	Difference
	mgms.	mgms.	mgms.
Nil	2.7	44.3	41.6
3P	23.	55.1	31.2
7P	43.7	69.6	25.9
L	−5.3	35.7	41.0
L, 3P	11.9	47.3	35.4
L, 7P	47.7	56.9	9.2
S	13.3	54.6	41.3
S, 3P	31.8	61.5	29.7
K	19.9	48.2	18.3
K, 3P	27.8	56.5	28.5
K, 7P	59.6	70.7	11.1

The general purpose of acid extraction methods is to determine the need of soils for phosphate fertilization, and the fundamental assumption is that the phosphorus soluble in the extracting solution is the store of phosphorus which is most readily available to plants. If this assumption is correct it is to be expected that the store of readily soluble phosphorus

[6] Acid extraction methods other than the Quebec extraction show the same differences in soluble phosphorus before and after the growth of plants, and hence fail in the same way to account for the phosphorus removed.

would diminish as phosphorus is removed by the plants. The data presented here show that this is not necessarily so. In no instance is the decrease in soluble phosphorus sufficient to account for the total removal by the plants; furthermore, the store of readily soluble phosphorus may remain constant or even increase while the plants are removing substantial amounts of phosphorus. However one may choose to interpret these data, it is ultimately some form of phosphorus other than that determined by dilute acid extraction that is supplying most of the phosphorus obtained by the plant.

To understand the behavior of the easily soluble phosphate one must bear in mind at all times that, although soluble in the dilute acid extractant, it is not in solution in the soil, but exists in an undissolved state. This particular fraction of undissolved phosphate will be in equilibrium with the soil solution under a certain set of conditions when it will tend neither to increase nor to decrease; such conditions were evidently approximated in the untreated soil during the pot culture experiment. Under another set of conditions the soil solution will be unsaturated with respect to the easily soluble phosphorus, when the latter will continuously pass into solution, fulfilling the tendency to restore equilibrium. Such conditions evidently exist when superphosphate has been added to the soil and a quantity of easily soluble phosphate formed which is not in equilibrium with the soil system, or when the environment of the native readily soluble phosphorus is changed, for example by addition of sulphur. From this point of view, soil phosphate should be regarded as available when it is actively in process of disappearing from the soil. Finally, conditions may be such that the solubility product of some readily soluble phosphate compound is exceeded in the soil solution, and an increase in the undissolved quantity of readily soluble phosphate will ensue so long as these conditions persist. In the experiment cited, such conditions were evidently brought about by the addition of calcium carbonate to the soil.

The same argument will, in its general application, embrace all the forms of inorganic phosphate that may be considered as existing in solubility equilibrium with the soil solution, and hence will apply indifferently to any method of acid extraction that may be proposed. Whence, then, in the experiment under consideration, did the phosphorus taken up by the plants arise?

We have recently shown (15) that a considerable part of the phosphorus of these soils exists in organic form as nucleotides. This finding provides a real basis for the belief that the cycle of phosphorus in the soil is similar in certain respects to that of nitrogen. In the case of nitrogen there exists an accumulation of relatively stable and inert forms which, in the course of a biological cycle, give rise to inorganic nitrogen compounds. These compounds may be utilized by plants, may be lost from the soil by leaching or by denitrification, or may again be built up into complex organic compounds by biological activity within the soil. Similarly, the breakdown of organic phosphorus molecules would give rise to phosphoric acid which, entering the soil solution, may be utilized by higher plants, or may react with basic soil constituents forming undissolved inorganic phosphates, or be resynthesized into organic compounds by soil micro-organisms. Such a concept provides a rational explanation of the results reported in this paper.

SUMMARY

Surface application of superphosphate to Quebec permanent pastures on brown forest soil results in an increase in the amount of readily soluble phosphate in the surface one-half inch layer of soil. In the years following fertilization this readily soluble phosphate gradually diminishes, so that three or four years after treatment the values approach that of the unfertilized soil. On the basis of our interpretation of the pot culture results, the readily soluble phosphate is to be considered available while it is in the process of decreasing. The soluble phosphate of untreated soil appears to be an equilibrium quantity, probably not varying significantly from year to year, and approached in the treated soil after the effectiveness of the application has worn off. The increase of wild white clover in the sward, and the yield increase over untreated pasture, are seen to be closely related to the amount of soluble phosphate produced by fertilization and remaining in the soil at the time of measurement.

The pot culture experiment has shown that the phosphorus uptake by pasture plants growing on this soil is not to be wholly attributed to the utilization of readily soluble phosphate. The phosphorus obtained by the plants was in all cases considerably more than could be attributed to decreases in the amount of readily soluble phosphate in the soil. The readily soluble phosphate may decrease, remain constant, or increase while the plants are withdrawing phosphorus. It is suggested that a considerable proportion of the phosphorus obtained by the plants came from the nucleotides known to exist in this soil. Decomposition of nucleotides would result in the release of phosphoric acid into the soil, thus providing a notable source of phosphorus for plant nutrition and the replenishing of inorganic phosphates in the soil.

ACKNOWLEDGMENT

The authors tender thanks to Professor R. Summerby for advising the design of the pot culture experiment, to Mr. W. F. Millinchamp who performed the statistical analyses, and to our several colleagues for their continued helpful interest.

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PRUNING STAKED TOMATOES

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[Received for publication March 14, 1938]

Tomato growing is mainly divided into three particular phases of production: field tomatoes for the cannery crop, from which the first ripe fruit is to a large extent shipped to the fresh fruit market; staked tomatoes for table use; and greenhouse tomatoes used entirely for the fresh fruit market. This report deals with staked tomatoes grown in the open, and describes various methods of pruning which have been tried in order to produce as early a crop as possible. Over a period of years there have been tested essentially four different methods, and within each group the main consideration has been the amount of pruning and the type of pruning in relation to the time at which the operation was performed. The factor of time, so far as literature reviewed by the writer is concerned, has not been considered previously.

LITERATURE REVIEW

Pruning tomatoes has formed the basis of numerous experiments with varying procedure. Thompson (1), using the Bonny Best variety, compared plants staked and pruned to a single stem to unpruned plants, and obtained a lower yield per plant when pruned, but increased earliness. When the number of pruned plants was more than double the number of unpruned ones the plot yield was greater for pruning. In reviewing the literature he reports seven workers covering the period 1892–1933 reporting a higher yield on unpruned than on pruned plants. Edmond (2), using the Marglobe variety, in Mississippi for one year found no appreciable difference between pruned and unpruned plots. Stucky in Georgia and Whipple and Schermerhorn in Montana report results in which the pruned plants produced a larger yield per plant than unpruned ones. In Montana the yield of ripe fruit was greater on pruned plants. The total yield of green and ripe fruit was, however, greatest on unpruned plants. These results indicate earliness from pruning and a short season which prevents much of the later maturing fruit from ripening. The evidence submitted by Thompson indicates generally that pruning under many conditions induces early ripening. There are, however, notable exceptions from some sections where pruning has reduced earliness. Magruder (3), using the Bonny Best variety, in comparing unpruned plants to those pruned to 1, 2 and 3 stems and staked, found that pruning increased earliness during the first four weeks of harvesting and that differences between amount of pruning were not large enough to warrant any but the least expensive treatment, one stem, being used. Watts (4), working at Fayetteville and Hope, Arkansas, used in successive years at Fayetteville the Norton, Marglobe and Break O'Day varieties, and at Hope the Gulf State Market variety. There were sixteen treatments with various degrees of training in these experiments. He divided the picking season into three periods, early, midseason and late; and between years, stations, and treatments

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obtained somewhat variable results, concluding that pruning reduced early and total yields at Fayetteville and that no significant differences showed at Hope. Training plants to stakes irrespective of the method of pruning increased earliness and yield at Fayetteville, but resulted in no differences at Hope. He further mentions that the different varieties used at the two stations may in part account for the lack of agreement of results. Olney (5), after three years' trial, concluded that some varieties, more than others, are influenced by pruning. Walker (6), working at Indian Head, Saskatchewan, used the Bonny Best and Alacrity varieties. He grew plants pruned to a single stem, stopped these at 1, 2 or 3 trusses, and compared results to plants which were not stopped. He concluded that severe pruning induced earliness but decreased yield.

METHODS AND MATERIALS

Experiment I

In this experiment there were 4 treatments; plants were stopped at 2 and 3 trusses, and unchecked plants trained to one and two stems. There was variation in size and number of plots throughout the years of this experiment. In 1927 and 1928 each treatment was systematically repeated twice in 30-foot rows with 10 plants to a row. In 1929, 1930 and 1931 each treatment was replicated 3 times on the above basis, using the same size of plot, and in 1932 and 1933 each treatment was replicated 4 times in 15-foot rows with 5 plants to a row.

Experiment II

There were 4 treatments in this group. Plants were stopped at 4, 6, 8 and 10 trusses when the respective numbers had formed, and no further terminal growth was allowed to develop. Four- and 6-truss plants were trained to a single stem, 8- and 10-truss plants were trained to 2 stems, except in 1932, when 3 stems were allowed to develop. This number, however, was found to be too many for staked plants. Each year there were 4 replicated plots in 15-foot rows with 5 plants for each treatment. During the first three years the plots were systematically distributed; in the last 2 years they were arranged at random in the form of a latin square.

Experiment III

There were four treatments in this group essentially the same as in II, but instead of stopping the plants when the respective number of trusses had formed all were allowed to develop 10 trusses on 2 stems and they were then stopped at tens and headed back to fours, sixes and eights. Plot size and arrangement was as in II.

Experiment IV

In this group, time of pruning was the essential feature. Plants were trained to a single stem and stopped at weekly intervals on 4 different dates. In 1931, eight trusses were allowed to develop before the first stopping was done. With this number of trusses it was found that the pruning was delayed until too late, so in subsequent years the first pruning was done when the sixth truss had formed. There were 4 dates of stopping

at weekly intervals. Plot size and arrangement was on the same basis as outlined for II and III.

The variety used throughout the experiment was the Bonny Best, except in 1936, when the seed package was wrongly named. The variety that year was a large, coarse, pink-colored one. The rows and distance between plants each year gave a spacing of 36 inches on the square. Experiments II, III, and IV were mainly an outcome of I in order to study the effect of time of pruning in relation to yield and maturity. The experiments were carried out from 1927 to 1936 inclusive. There were no results in 1934, due to the crop being destroyed by blight.

RESULTS

In order to save space, yearly tables are omitted and only a final summary is given for each experiment. The crop yields given, unless otherwise stated, are for totals of marketable fruit at weekly intervals.

Experiment I. Plants Trained to 2 and 3 Trusses and 1 and 2 Stems

TABLE 1.—TOTAL YIELD AT WEEKLY INTERVALS FOR SEVEN CROP YEARS

Plants trained to	Period 1		Period 2		Period 3		Period 4		Period 5		Period 6		Total for season	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
2 trusses	50	8	142	11	238	7	319	11	358	12	378	13	400	2
3 trusses	50	2	137	11	260	9	428	0	564	10	657	0	714	8
1 stem	45	12	137	3	285	1	450	5	663	12	985	3	1260	5
2 stems	34	4	100	15	239	0	448	2	721	14	1168	2	1757	14

Table 1 summarizes very closely the trends which were obtained from year to year. The only noteworthy exception was in 1929, when at the second period 2-stem plants gave the highest yield and maintained that position throughout the balance of the season. As indicated above, severe pruning to 2 and 3 trusses induces early ripening during the first 10 to 14 days of the season. Following this period the returns fall off, due to light yield, and from the third to fourth interval plants trained to one stem come into the lead and maintain this position up to the fifth or sixth interval, at which time 2-stem plants gave the highest yield and maintained this superiority for the balance of the season. In other words, pruning to two and three trusses gave the largest amount of ripe fruit during the first 2 weeks of ripening, single stem plants led during the third and fourth week, and two-stem plants produced more than any of the above after the fifth week of ripening.

Under the climatic conditions where this experiment was conducted a comparatively small but quite variable percentage of fruit matures during the first 2 weeks of ripening. This condition is markedly influenced by temperature when the first blossoms open which to a large extent regulates the number of blossoms which set fruit. Also directly bearing on the percentage of the total crop during the first 2 weeks is the length of the picking season, which is largely influenced by rain in September and disease. When there is a high precipitation much of the September crop

is lost by cracking and disease. While there is ordinarily a premium for early ripe fruit there must as well be a satisfactory yield, and for practical purposes single stem plants which average from 6 to 8 trusses best meet this requirement. Throughout this and the other experiments referred to hereafter it was quite frequently noticed that one or two ripe fruits may occur on any treatment well in advance of others irrespective of treatment. Such fruits are considered to be from fortuitous setting rather than due to treatment.

Experiment II. Plants Stopped at 4, 6, 8 and 10 Trusses

In view of the fact that pruning in experiment I produced an effect on maturity, it was felt that the time of pruning in relation to the method might further modify results. With this in mind experiments II, III and IV were initiated. Experiments II and III received identical pruning. The time factor was the only variable apart from the four treatments, number of trusses in each group. A summarized table of results of plants stopped at 4, 6, 8 and 10 trusses is given below.

TABLE 2.—TOTAL YIELD OF RIPE FRUIT AT WEEKLY INTERVALS, 5 CROP YEARS

Plants trained to	Period 1		Period 2		Period 3		Period 4		Period 5		Period 6	
	lb.	oz.	lb	oz.	lb.	oz.	lb.	oz	lb.	oz.	lb.	oz.
4 trusses	44	7	136	6	227	9	312	0	404	6	495	12
6 trusses	35	4	132	3	247	1	344	3	486	10	658	14
8 trusses	34	11	130	0	242	5	377	10	518	9	770	8
10 trusses	37	14	129	0	234	8	339	3	480	4	797	11

The above table very closely approximates the results obtained in tabular form for each year with the exception of 1936, when a different variety was used. In 1936 ten-truss plants gave the highest yield throughout the season, which indicates the possibility of varying response to pruning with certain varieties. In 1932 blight destroyed a large percentage of the later crop with the result that 10-truss plants gave the lowest yield. The trend of results here is the same as shown in Table 1, maturity being hastened by pruning. In order to compare the effect of time of pruning reference must be made to Experiment III.

Experiment III. Plants Pruned Back to 4, 6, 8 and 10 Trusses after 10 Had Formed

The results for amount of pruning in this test were the same as those previously referred to, namely, the more severe pruning giving the largest amount of ripe fruit in the early part of the season. In both this and the previous experiment best results, considering earliness and yield, were from plants trained to 6 or 8 trusses. This is the average number of fruiting trusses which bear fruit in plants pruned to a single stem when they are allowed to develop their maximum height. The actual number of fruiting trusses depends on the setting of fruit on those first formed, and on disease

and climatic conditions at the end of the season. In order to compare the total yield of plants in experiments II and III Tables 3 and 4 are presented.

TABLE 3.—TOTAL AND YEARLY YIELD OF PLANTS STOPPED AT 4, 6, 8 AND 10 TRUSSES

—	4 trusses		6 trusses		8 trusses		10 trusses	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
1931	102	3	160	11	194	1	226	3
1932	105	4	152	13	185	6	182	10*
1933	88	12	82	1	96	10	81	0*
1935	57	10	93	7	108	13	109	10
1936	141	15	169	14	185	10	198	4
Total	495	12	658	14	770	8	797	11

* Low yields are due to blight infection during the latter part of the cropping season.

TABLE 4.—TOTAL AND YEARLY YIELD OF PLANTS PRUNED BACK TO 4, 6, 8 AND 10 TRUSSES

—	4 trusses		6 trusses		8 trusses		10 trusses	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
1931	110	7	160	5	204	6	227	12
1932	110	3	162	6	169	12	165	8
1933	101	3	113	8	113	5	91	1
1935	72	6	112	4	123	9	118	9
1936	147	8	210	1	243	3	232	2
Total	541	11	758	8	854	3	835	0

Tables 3 and 4, with two exceptions in 1932, indicate a heavier yield of fruit from plants which are allowed to develop up to 10 trusses and are then headed back than from plants stopped when a lesser number of trusses have formed. The most probable explanation for this performance is the increase in size of fruit due to increased leaf area, as referred to by Gustafson and Stoldt (7) who found a direct correlation between size of fruit and leaf area.

Experiment IV. Pruning at Weekly Intervals

In this experiment plants were trained to a single stem and divided into 4 groups, and groups were stopped or pruned back at weekly intervals. The first stopping was done when the sixth truss had formed. This is at approximately the time when the first fruits are in a semi-ripe condition. Results for 5 crop years gave no difference in earliness from any one date treatment. There were, however, as indicated in Table 5, differences in yield.

TABLE 5.—TOTAL AND YEARLY YIELDS, PRUNING TO 6 TRUSSES AT WEEKLY INTERVALS

—	1st pruning		2nd pruning		3rd pruning		4th pruning	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
1931	219	8	234	11	196	15	212	11
1932	135	0	135	0	145	12	153	1
1933	111	4	112	10	107	9	116	10
1935	111	10	120	2	99	3	133	1
1936	159	8	154	15	148	0	176	10
Total	736	14	757	6	697	7	792	1

The summary in Table 5 closely approximates individual plot yields from the yearly data. With the exception of 1931 the fourth pruning each year gave the highest yield and is further substantiation of the results in experiment III that delayed pruning has definite advantages in increasing yields. The third pruning is an exception to the above for which no satisfactory explanation can be offered.

DISCUSSION AND CONCLUSIONS

Tomato plants of the Bonny Best variety are definitely affected by pruning. In 1936 when a different variety was used there was some evidence that there may be a definite varietal response to pruning practices, as is referred to by Olney (5). With plants pruned to 4 or fewer trusses there has been earlie rmaturing fruit than with those having a greater fruiting area. Maturity is hastened and yield decreased in proportion to the amount of pruning, which results are in accordance with those of Walker (6). These results are not in agreement with those obtained by all other workers some of whom report no increased earliness due to pruning. An important factor not always enumerated in these other experiments is the length of periods into which the season is divided. In the work reported in this paper, had the season been divided into comparatively long periods of 3 to 4 weeks duration, earliness for severe pruning would not have manifested itself, and results at four to five weeks would have been discordant between plants trained to one and two stems. There has also been with severe pruning, 2 and 3 trusses, a marked tendency for the fruits to become affected by sunscald. Irrespective of treatment, individual ripe fruits will mature as early on any one treatment as another, even though a given treatment will on the whole produce a generally earlier crop. Thompson (1) working in New York obtained similar results. Where plants are pruned back to 4 or 6 trusses best results are obtained when growth is allowed to develop on 2 stems and when 10 trusses have formed head back to the required number. This practice does not increase earliness but it does increase the yield. Thompson (1) reports size of fruit increased by pruning. Watts (4) found no difference in average size of fruit from any system of pruning or training. Walker (6) obtained increased size of fruit from severe pruning, while Gustafson and Stoldt (7), working under greenhouse conditions, definitely correlated size of fruit increasing with the amount of foliage. An additional advantage from delayed thinning is a saving in labour, as there is no need to go over the plants at frequent intervals to cut out small shoots. The bulk of the work can be done in fewer operations. Thompson (1) on the other hand reports that unless the shoots are pruned out while small much of the advantage will be lost. Experiments III and IV in this paper show increased yield for delayed pruning. The plants, though, were definitely pruned to either one or two stems within a month after the date of transplanting to the open. Unless there is a high premium for the first fruit, yield cannot be unduly sacrificed, and further when there is not an adequate market at a remunerative price for the late maturing crop the practice of growing for highest yields is equally unsatisfactory. The results of these experiments have shown that the middle course is the best. This consists of pruning plants to a single stem and allowing them to develop to their maximum height. Normally such plants will bear

fruit on 6 to 8 trusses. Data from unpublished experiments have shown that the maximum yield from a given area for plants so trained is when they are spaced at 12 inches in rows 3 feet apart.

SUMMARY

Evidence has been presented to show that fruiting habits of tomato plants are influenced by pruning. The methods involved have included the amount of pruning and the time at which the work is done, and have chiefly indicated the following:

1. Maturity is hastened by the most severe pruning practices.

2. Commensurate with yields and sunscald injury too severe pruning can be done.

3. Delayed pruning gives increased yields.

4. Unchecked plants trained to a single stem have given the most satisfactory results, considering earliness and total yield.

5. The evidence, while fragmentary, indicates the possibility of varietal differences in response to pruning.

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DOWNY MILDEW OF THE ROSE IN BRITISH COLUMBIA[1]

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[Received for publication March 3, 1938]

In July, 1937, downy mildew of the rose, *Peronospora sparsa* Berk. was observed in a garden in West Vancouver, British Columbia, where it did considerable damage to the varieties Portadown and Lord Lonsdale. Slight infection was also observed on the varieties Mrs. Gladys Peach, Mrs. H. Morse, Mrs. Laxton, Lal, Crimson Glory, Trigo, and Mrs. C. Lamplough. The garden referred to is situated in a low area, where air drainage is poor and the humidity high. The location provided an ideal environment for the development of the disease under outdoor conditions. Slight symptoms have since been observed on plants grown outdoors in two other localities, indicating that it may be widely distributed.

The disease has been previously reported from Europe and America, but appears to be mostly confined to greenhouses. Eriksson (1) in referring to infection in greenhouses states that "in 1884 a grower in Denmark lost more than two thousand rose trees."

Symptoms of the disease were found on the leaves, stems, and flowers. Affected leaves showed pale red to purplish red, irregular spots and areas on the laminas and frequently along the veins. These diseased areas differed from those of black spot caused by *Diplocarpon Rosae* (Lib.) Wolf. in being lighter in colour, less defined and not fibrillose along the margins (Figure 1). Infection symptoms on the stems appeared as reddish to purplish areas, and on the flowers as brown spots or areas on the petals. Most of the diseased flowers were spoiled, particularly when infection had occurred in the early bloom stage.

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FIGURE 1. A. Symptoms of Black Spot, *Diplocarpon Rosae* on rose leaf.
B. Symptoms of Downy Mildew, *Peronospora sparsa* on rose leaves.

SCIENTIFIC AGRICULTURE

Vol. XVIII JULY, 1938 No. 11

THE DIGESTIBILITY OF CANADIAN FEEDING STUFFS.

IV: RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES

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[Received for publication January 31, 1938]

The experiments reported in this paper were undertaken to determine the comparative digestibility of the nutrients of raw potatoes and of a dried potato product; also to determine the effect on the digestibility, if any, of soaking the dried potatoes before feeding.

The raw potatoes were graded, edible potatoes grown on the Central Experimental Farm, Ottawa. The dried potatoes were obtained from a fruit dehydrating plant by the Kentville Experimental Station, Nova Scotia. The potatoes had been pulped and placed on trays in a steam dehydrator. The inlet temperature of the dehydrator was 180° F. and the outlet temperature was 165° F. They were ground to pass a one-fifth inch mesh sieve with 24% passing a one-sixtieth inch mesh. The soaked dried potatoes were the above product soaked for 12 hours before feeding at a ratio of 2 parts by weight of water to 1 part of dried potatoes.

LITERATURE

The potato has been grown primarily for human consumption. Livestock feeders, however, have utilized surplus production and cull potatoes for all classes of livestock. They have been fed raw, cooked, dehydrated, and pressed and dehydrated. Both the potatoes and the stalks and leaves have been made into ensilage. By-products of starch manufacture have been marketed as a stock feed and also a by-product resulting from the extraction of certain nitrogenous substances from the potato. A German product known as "Kartoffelschlempe" is made from potatoes, malt and yeast.

A number of investigators have determined the digestibility of potatoes and of various potato products. Their data have been compiled in Table 1. These data indicate that swine, sheep, cattle and horses all digest the carbohydrates of the potato very efficiently. Swine gave higher coefficients of digestibility for nitrogen-free extract than did other classes of livestock.

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TABLE 1.—COEFFICIENTS OF DIGESTIBILITY OF POTATOES AND POTATO PRODUCTS
(Coefficients in per cent)

Type of potato product	Authority	Dry matter	Organic matter	Nitrogen	Crude fibre	N-free extract
Determinations with Swine						
Raw	Snyder (8)	97.0	—‡	84.5	—	—
Cooked	Snyder (8)	95.0	—	82.0	—	—
Flakes*	Fingerling (2)	—	95.1	70.5	84 9	98.3
Cuttings†	Fingerling (2)	—	92.8	29.2	70.3	96.7
Dried	Kellner, Just, Eisenkolbe and Poppe (4)	—	91.3	58.8	73.2	94.5
Pressed dried	Kellner and Neumann (5)	—	94.5	26.7	85.3	97.9
Pressed dried	Kellner and Neumann (5)	—	90.4	—	72.7	96 9
Mean values		96.0	92 8	58.6	77.3	96 9
Determinations with Sheep						
Raw	Woods (15)	76.0	77.0	44 6	—	90 3
Raw	Völtz and Dietrich (10)	—	84 0	44 0	—	95.0
Cooked	Woods (15)	80.0	81.0	43.4	—	92 1
Cooked	Völtz and Dietrich (10)	—	80 0	59 0	13 0	96.0
Cooked	Watson and Horton (12)	—	88.1	67.8	—	94.2
Dried	Kellner, Volhard and Honcamp (6)	80.1	81.5	19.5	—	92.0
Dried	Kellner, Just, Eisenkolbe and Poppe (4)	—	86.5	31.9	—	94.4
Mean values		78.7	82.6	44.3	—	93.4
Determinations with Beef Cattle						
Flakes	Fingerling (2)	79.7	81.4	—	—	92.0
Cuttings	Fingerling (2)	84.0	85.3	30.9	—	95.1
Mean values		81.9	83.4	—	—	93.6
Determination with Horses						
Steamed	Engler (1)	71.9	73.0	72.1	39.2	90.7
Determination with Poultry						
Raw	Völtz and Yakuwa (11)	—	78.3	46.9	—	84.5

* Cut, pressed and dehydrated potatoes.
† Cut and dehydrated potatoes.
‡ Coefficients either not given or else not within the range of 0 to 100.

EXPERIMENTAL

Experiments were conducted in 1935, 1936 and 1937. In 1935, the coefficients of digestibility of ground, dried potatoes were determined with four grade Shorthorn steers numbered, in this experiment, 5, 6, 7 and 8.

Their average live weights were 537, 585, 600 and 601 kilogrammes, respectively. The basal ration was composed of a mixed legume and grass hay and soybean oil meal, the digestibility of which ration had been determined in a previous experiment (13). The total daily ration per animal was five kilogrammes of hay, one kilogramme of soybean oil meal and three kilogrammes of dried potatoes.

In 1936 the coefficients of digestibility of pulped raw potatoes were determined with two steers, numbered B and D, from the group described by Watson *et al.* in a previous paper (14). The potatoes were washed, drained over night and pulped previous to feeding. A mixed legume and grass hay of known digestibility (14) was used as the basal ration. Five kilogrammes of hay and fourteen kilogrammes of raw potatoes were fed per animal per day.

In the 1937 experiment the coefficients of digestibility of raw potatoes, dried potatoes and soaked dried potatoes were determined with four grade Shorthorn steers, numbered H, E, F and G in this report. They were 2½ years old and averaged 564, 533, 450 and 449 kilogrammes, respectively, in live weight. The comparisons were made by a 4 × 4 randomized latin square. The basal ration was a mixed legume and grass hay. The hay alone was fed at a level of 7.0 kilogrammes per animal per day. In the mixed rations the hay was fed at a level of 5.0 kilogrammes, the raw potatoes at 12.0 kilogrammes and the dried potatoes at 3.2 kilogrammes per day. The schedule of the experiment is given in Table 2.

TABLE 2.—SCHEDULE OF THE 1937 EXPERIMENT
COMPOSITION OF RATION

—	Animal H	Animal E	Animal F	Animal G
Period 1	Hay and raw potatoes	Hay and soaked dried potatoes	Hay and dried potatoes	Hay
Period 2	Hay and dried potatoes	Hay and raw potatoes	Hay	Hay and soaked dried potatoes
Period 3	Hay and soaked dried potatoes	Hay	Hay and raw potatoes	Hay and dried potatoes
Period 4	Hay	Hay and dried potatoes	Hay and soaked dried potatoes	Hay and raw potatoes

RESULTS

In all experiments a preliminary period of 12 to 14 days was followed by a collection period of 12 days.

The experimental data are presented in Tables 9 to 14 in the appendix.

Table 3 gives the average composition in percentage of dry matter for raw and dried potatoes fed in 1935, 1936 and 1937.

TABLE 3.—AVERAGE CHEMICAL COMPOSITION OF DRIED POTATOES AND RAW POTATOES
(Mean of five values of dried potatoes and six of raw potatoes)

——	Original moisture, %	Percentage of dry matter*				
		Protein (N × 6.25)	Ether extract	Crude fibre	N-free extract	Ash
Dried Potatoes						
Mean	11.24	10.88	0.36	2.41	80.97	5.38
Coeff. of var.†	8.24	9.46	10.47	5.69	1.31	6.57
Standard error	±0.41	±0.46	±0 02	±0.06	±0.47	±0.16
Raw Potatoes						
Mean	78.34	12.65	0.25	2.20	79.90	5.01
Coeff. of var.	1.41	2.80	38.78	4.87	0.64	5.39
Standard error	±0.45	±0.14	±0.04	±0.04	±0.21	±0.11

* Analyses of raw potatoes made on aliquots dried at 70° C. to air-dry weight.
† Fisher's methods (3) have been used in the statistical treatment of the data.

A summary of the coefficients of digestibility for the 1935 and 1936 expe,iments is given in Table 4.

TABLE 4.—COEFFICIENTS OF DIGESTIBILITY OF DRIED POTATOES AND OF RAW POTATOES
(Coefficients in per cent)

——	Dry matter	Organic matter	Nitrogen	N-free extract
Dried Potatoes—1935				
Animal No. 5	85.0	85.9	35.0	92 9
Animal No. 6	83.4	84.3	32.1	92.5
Animal No. 7	83.9	84.5	28.8	93 6
Animal No. 8	82.6	83.2	41.9	91.7
Mean	83.7	84.5	34.5	92.7
Coeff. of variation	1.20	1.31	16.16	0.86
Standard error	±0.50	±0.55	±2.79	±0 40
*Raw Potatoes—1936**				
Animal No. B	88.7	89.4	71.1	95.6
Animal No. D	86.9	87.9	68.8	95.6
Mean	87.8	88.7	70.0	95.6

* Nitrogen coefficients calculated on the basis of original nitrogen. (See Table 10 in the appendix.)

In Table 5 the coefficients of digestibility of hay and of the potatoes, calculated from the mixed ration, for the 1937 experiment have been arranged by periods and by animals. In Table 6 the average coefficients of digestibility for the various rations have been presented, while in Table 7 the analysis of variance with the significant differences between two means has been summarized.

TABLE 5.—COEFFICIENTS OF DIGESTIBILITY OF HAY, RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES ARRANGED BY PERIODS AND BY ANIMALS
(Coefficients in per cent. Treatments shown by Roman Numerals*)

—	Animal	Period 1		Period 2		Period 3		Period 4		Mean
Dry matter	H	(IV)	90.6	(II)	82.3	(III)	85.3	(I)	56.8	78.8
	E	(III)	85.3	(IV)	85.7	(I)	57.2	(II)	87.5	78.9
	F	(II)	83.9	(I)	55 3	(IV)	86.3	(III)	85.0	77.6
	G	(I)	54.5	(III)	85 2	(II)	89.1	(IV)	86.8	78.9
	Means		78 6		77.1		79.3		79.0	78.55
Organic matter	H	(IV)	92.2	(II)	83.2	(III)	86.7	(I)	58.1	80.1
	E	(III)	86.8	(IV)	86.1	(I)	58.2	(II)	89.1	80.1
	F	(II)	85.8	(I)	56 4	(IV)	87.7	(III)	87.0	79.2
	G	(I)	56.0	(III)	86.8	(II)	91.1	(IV)	88.9	80.7
	Means		80.2		78 1		80.9		80.8	80.01
Nitrogen	H	(IV)	69 1	(II)	54.9	(III)	52.7	(I)	61.6	59.6
	E	(III)	51.7	(IV)	66 2	(I)	60.6	(II)	61.1	59.9
	F	(II)	51 1	(I)	54 3	(IV)	47.6	(III)	44.7	49.4
	G	(I)	56.8	(III)	53 3	(II)	54.5	(IV)	64.5	57.3
	Means		57 2		57 2		53 9		58 0	56.54
N-free extract	H	(IV)	95 3	(II)	90 3	(III)	93.1	(I)	69.8	87.1
	E	(III)	94 3	(IV)	93.7	(I)	69.1	(II)	95.6	88.2
	F	(II)	94.0	(I)	67.9	(IV)	93.1	(III)	95.5	87.6
	G	(I)	68.0	(III)	93.0	(II)	96.2	(IV)	97.4	88.7
	Means		87.9		86.2		87.9		89.6	87.89

* I—Hay alone; II—Dried potatoes; III—Soaked dried potatoes; IV—Raw potatoes.

TABLE 6.—AVERAGE COEFFICIENTS OF DIGESTIBILITY* FOR EACH RATION IN PERIODS 1, 2, 3, AND 4

Ration	Dry matter	Organic matter	Nitrogen	N-free extract
Hay	56.0	57.2	58.3	68.7
Dried Potatoes	85.7	87 3	55.4	94.0
Soaked dried potatoes	85.2	86.8	50.6	94.0
Raw potatoes	87.4	88.7	61.9	94.9

(* Coefficients in per cent.)

TABLE 7.—STATISTICAL ANALYSIS OF DATA IN TABLES 5 AND 6

—	Variance due to	Degrees of freedom	Sums of squares of deviations	Variance	Significant difference between two means*
Dry matter	Ration	3	2728.68	909.56	4.29
	Period	3	12 84	4.28	
	Animal	3	4.84	1.61	
	Error	6	36.98	6.16	
	Total	15	2783 34		

TABLE 7.—STATISTICAL ANALYSIS OF DATA IN TABLES 5 AND 6—*Concluded*

—	Variance due to	Degrees of freedom	Sums of squares of deviations	Variance	Significant difference between two means*
Organic matter	Ration	3	2780.24	926.75	4.11
	Period	3	20.40	6.80	
	Animal	3	4.59	1.53	
	Error	6	33.80	5.63	
	Total	15	2839.03		
Nitrogen	Ration	3	273.64	91.21	6.78
	Period	3	39.89	13.30	
	Animal	3	288 84	96.28	
	Error	6	92.03	15.34	
	Total	15	694 40		
N-free extract	Ration	3	1968.24	656.08	3.08
	Period	3	23.12	7.71	
	Animal	3	5.84	1.95	
	Error	6	19 02	3.17	
	Total	15	2016.22		

* Goulden, C. H.—Methods of Statistical Analysis (1936) pp. 97–98.

The effects of animal and of period upon the coefficients of digestibility of dry matter, organic matter and nitrogen-free extract were not significant. The coefficients of digestibility of the nitrogen obtained with animal F were significantly lower than those obtained with animals H, E and G. The average coefficient of digestibility of nitrogen of raw potatoes was significantly higher than that of soaked dried potatoes. The coefficients of digestibility of the dry matter, organic matter and nitrogen-free extract of dried potatoes, soaked dried potatoes and raw potatoes were, in the case of each nutrient, of the same order.

Table 8 is a summary of all the coefficients of digestibility obtained from the three experiments. It includes a second determination of the

TABLE 8.—AVERAGE COEFFICIENTS OF DIGESTIBILITY FOR RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES IN PER CENT

—	Number of values	Coefficients of digestibility			
		Dry matter	Organic matter	Nitrogen	N-free extract
Raw potatoes—1936–37					
Mean	7	87.7	89.0	65.0	95.1
Coeff. of variation		1.92	2.26	12.22	1.48
Standard error		±0.64	±0.76	±3.00	±0.53
Dried potatoes—1935 and 1937					
Mean	8	84.7	85.9	44.9	93.4
Coeff. of variation		2.84	3.30	26.93	2.09
Standard error		±0.85	±1.00	±4.28	±0.69
Soaked dried potatoes—1937					
Mean	4	85.2	86.8	50.6	94.0
Coeff. of variation		0.17	0.15	7.88	1.25
Standard error		±0.07	±0.07	±1.99	±0.59

coefficients of digestibility of raw potatoes with animal H of the 1937 experiment.[5] The average coefficient of digestibility for the nitrogen of raw potatoes was significantly higher than that for dried potatoes or soaked dried potatoes.

DISCUSSION OF RESULTS

From the data in Table 3 it is concluded that, on the dry matter basis, the dried potatoes were lower in total protein than the raw potatoes but equal to them in regard to the other constituents. The difference in protein may not be entirely due to the process of drying since the dried potatoes and the raw potatoes were not from the same crop.

The data in Table 8 show that the potato is a highly digestible carbohydrate feed. Drying had no deleterious effect upon the digestibility of the carbohydrate of the potato. The coefficients of digestibility for the nitrogen of raw potatoes were significantly higher than those for dried potatoes or soaked dried potatoes. In the 1935 experiment the coefficients of digestibility of the nitrogen of the dried potatoes were lower than those determined in 1937. The basal ration of the 1935 experiment contained soybean oil meal and the digestibility of the nitrogen of this latter feed may have been modified by the starch of the potatoes. This would affect the digestibility of the nitrogen of the dried potatoes as calculated.

The 1937 results show that soaking the dried potatoes did not increase the availability of the potato nutrients. Soaking is a time-consuming process due both to the time involved in soaking and to the necessity of feeding as a separate entity of the ration. The authors, therefore, recommend that dried potatoes be fed dry and mixed with the other ingredients of the grain ration for cattle.

Monetary values have been assigned to raw potatoes using the method of Petersen (7) as applied to Canadian conditions by Stothart (9). In employing this method it was assumed that, in feeding practice, units of protein and non-protein nutrients in potatoes were equivalent to units in barley and linseed oil meal. With barley worth $26.00 and linseed oil meal worth $34.00 per ton of dry matter, potatoes would be worth $25.60 per ton of dry matter. With barley at $35.00 and linseed oil meal at $43.00, potatoes would be worth $34.88 per ton of dry matter. Expressed on the original basis, raw potatoes would be worth 17 cents and 23 cents, respectively per bushel.

SUMMARY

With grade Shorthorn steers as experimental animals, digestibility trials were conducted with raw potatoes, dried potatoes and soaked dried potatoes.

The carbohydrate nutrients of the potato were highly digestible and the coefficients of digestibility obtained in this study were of the same general order as those obtained by other investigators.

It was shown that the drying of potatoes had no practical deleterious effects upon the availability of the nutrients of the potato.

Soaking the dried potatoes did not increase their value as a feed for beef cattle.

[5] Table 14 in the Appendix.

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APPENDIX

TABLE 9.—CHEMICAL COMPOSITION OF FEEDING STUFFS

Year	Period	Original moisture %	Percentage of dry matter				
			Protein (N×6 25)	Ether extract	Crude fibre	N-free extract	Ash
			Hay				
1935		7.27	12.22	2.56	30.31	46.93	7.98
1936		11.06	12.67	1.80	35.92	41.50	8 11
1937	1	13.23	12 78	2.47	31.88	45.67	7.20
1937	2	13.40	11.95	2 45	32.62	45.94	7.04
1937	3	13.94	12.84	2.44	33.60	43.75	7.37
1937	4	14 17	14.03	2.43	31.79	44.09	7 66
1937	5	13.46	13.32	2.61	31 65	44.69	7.73
			Soybean Oil Meal				
1935		8.01	40.58	6.31	8.52	37.11	7.48
			Dried Potatoes				
1935		10.98	9.12	0.36	2.58	82.84	5.10
1937	1	12.02	11.66	0.34	2.33	80.44	5.23
1937	2	12.37	11.58	0.32	2.24	80.81	5.05
1937	3	10.20	11.04	0.42	2.38	80.38	5.78
1937	4	10.61	11.00	0.37	2.51	80.38	5.74

TABLE 10.—CHEMICAL COMPOSITION OF RAW POTATOES

Year	Period	Analysis of original material		Percentage of dry matter*				
		Moisture, %	Nitrogen† %	Protein (N×6.25)	Ether extract	Crude fibre	N-free extract	Ash
1936		76.24	0.529	12.87	0.43	2.07	79.87	4.76
1937	1	78.18	0.443	12.36	0.25	2.21	79.71	5.47
1937	2	78.79	0.458	12.81	0.16	2.28	80.01	4.74
1937	3	79.43	0.398	11.66	0.17	2.33	80.75	5.09
1937	4	78.69	0.452	12.89	0.24	2.07	79.88	4.92
1937	5	78.73	0.464	13.29	0.25	2.21	79.17	5.07

* Analyses on aliquot samples dried at 70° C. to air-dry weight.
† All nitrogen coefficients of digestibility calculated from these original nitrogens.

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF DRIED POTATOES, 1935
(Collection period of 12 days; weights in kilogrammes; coefficients in per cent.)

——	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
In feeds							
Hay	60.000	55 638	51 198	1.088	1.422	16.866	26.112
Soybean oil meal	12 000	11.039	10 213	0.717	0.696	0.941	4.483
Dried potatoes	36 000	32 047	30.413	0.468	0.115	0.828	26.546
Total	108.000	98 724	91 824	2.273	2.233	18 635	57.141
In feces							
Animal No. 5	194.038	27.980	24.654	0.843	0.689	10.403	8.919
Animal No. 6	204.202	28 485	25.142	0.857	0.674	10 608	9.046
Animal No. 7	205.590	28.340	25.065	0.872	0.629	10.823	8.752
Animal No. 8	205.173	28.739	25.461	0 811	0.687	10.997	9.258
*Coefficients of digestibility of,**							
Hay		61.4	62.7	58.8	57 8	42.4	76.0
Soybean oil meal		84 6	87.6	87.3	87.8	106.0	80.9
Digested from							
Hay		34 162	32.101	0 640	0.822	7.151	19.845
Soybean oil meal		9.339	8.947	0.626	0.611	0.995	3.703
Total		43.501	41.048	1.266	1.433	8.146	23.548
Digested from dried Potatoes							
Animal 5		27.243	26 122	0.164	0 111	0.086	24.674
Animal 6		26.738	25.634	0.150	0.126	–	24.547
Animal 7		26.883	25.711	0.135	0.171	–	24.841
Animal 8		26.484	25.315	0.196	0.113	–	24.335
Coefficients of digestibility of dried potatoes							
Animal 5		85.0	85.9	35.0	96.5	10.4	92.9
Animal 6		83.4	84.3	32.1	109.6	–	92.5
Animal 7		83.9	84.5	28.8	148.7	–	93.6
Animal 8		82.6	83.2	41.9	98.3	–	91.7

* Sci. Agr. 17, 1, (1936).—1934 results.

TABLE 12.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, 1936
(Collection period of 12 days; weights in kilogrammes; coeficients in per cent.)

—	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
In feeds							
Hay	60.000	53.364	49.036	1.081	0.961	19.168	22.146
Raw potatoes	168.000	39.917	38.017	0.889	0.172	0.826	31.882
Total	228.000	93.281	87.053	1.970	1.133	19.994	54,028
In feces							
Animal B	178.289	30.194	27.223	0.714	0.616	12.688	9.973
Animal D	222.331	30.915	27.799	0.734	0.652	12.935	9.973
Coefficient of digestibility of Hay*		51.9	52.7	57.7	36.8	41.7	61.3
Digested from							
Hay		27.696	25.842	0.624	0.354	7.993	13.575
Digested from raw potatoes							
Animal B		35.391	33.988	0.632	0.163	–	30.480
Animal D		34 670	33.412	0.612	0.127	–	30.480
Coefficient of digestibility of raw potatoes							
Animal B		88.7	89.4	71.1	94.8	–	95.6
Animal D		86.9	87.9	68.8	73 8	–	95.6

* From Sci. Agr. 18 : 10; 586. (1935–36 results.)

TABLE 13.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF HAY, 1937
(Collection period of 12 days; weights in kilogrammes; coefficients in per cent.)

—	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
In hay							
Period 1	84.000	72.887	67.639	1 490	1.800	23.236	33.287
Period 2	84 000	72.744	67.623	1.391	1.782	23.729	33.419
Period 3	84.000	72.290	66.962	1.485	1.764	24.289	31.627
Period 4	84.000	72.097	66.574	1.619	1.752	22.920	31.788
In feces							
Animal H (4)*	193.952	31.158	27.865	0.622	0.816	13.843	9.587
Animal E (3)	170.974	30.966	27.968	0.585	0.793	14.009	9.779
Animal F (2)	230.830	32.531	29.512	0.636	0.823	14.401	10.735
Animal G (1)	190.549	33.147	29.756	0.644	0.925	14.233	10.644
Coefficient of digestibility							
An mal H		56.8	58.1	61.6	53.4	39.6	69.8
Animal E		57.2	58.2	60.6	55.0	42.3	69.1
Animal F		55.3	56.4	54.3	53.8	39.3	67.9
Animal G		54.5	56.0	56.8	48.6	38.7	68.0
Mean		56.0	57.2	58.3	52.7	40.0	68.7

* Number of period in brackets.

TABLE 14.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES—1937

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)

—	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
In hay							
Period 1	60.000	52.062	48.314	1.064	1.286	16.597	23.777
Period 2	60.000	51.960	48.302	0.993	1.273	16.949	23.870
Period 3	60.000	51.636	47.830	1.061	1.260	17.350	22.591
Period 4	60.000	51.498	47.553	1.156	1.251	16.371	22.705
Period 5	60.000	51.924	47.910	1.107	1.355	16.434	23.205
In raw potatoes							
Period 1	144.000	31.421	29.702	0.638	0.079	0.694	25.046
Period 2	144.000	30.542	29.094	0.659	0.049	0.696	24.437
Period 3	144.000	29.621	28.113	0.573	0.050	0.690	23.919
Period 4	144.000	30.686	29.176	0.650	0.074	0.635	24.512
Period 5	144.000	30.629	29.076	0.668	0.077	0.677	24.249
In dried and soaked dried potatoes							
Period 1	38.400	33.784	32.017	0.630	0.115	0.787	27.176
Period 2	38.400	33.650	31.951	0.623	0.108	0.754	27.193
Period 3	38.400	34.483	32.490	0.609	0.145	0.821	27.717
Period 4	38 400	34.326	32.356	0 604	0.127	0.862	27.591
Digested from hay							
Period 1		29.155	27.636	0.620	0.678	6.639	16.335
Period 3		29.098	27.629	0.579	0.671	6.780	16.399
Period 3		28.916	27.359	0.619	0.664	6.940	15.520
Period 4		28.839	27.200	0.674	0.759	6.548	15.598
Period 5		29.077	27.405	0.645	0.714	6.574	15.942
In feces of raw potato ration							
Animal H (1)*	168.899	25.849	22.985	0.641	0.734	10.050	8.615
Animal E (2)	180.961	27.236	24.730	0.637	0.616	11.445	9.007
Animal F (3)	232.330	26.787	23.940	0.742	0 664	10.747	8.725
Animal G (4)	206.965	26.712	23.600	0.713	0 673	11.179	7.746
Animal H (5)	199.027	26.283	23.245	0.680	0.712	10.227	8.529
Digested from raw potatoes							
Animal H (1)		28 479	27.395	0.441	–	0.602	23.873
Animal E (2)		26.168	25.037	0.436	0.035	–	22.901
Animal F (3)		25.554	24.644	0.273	–	0.353	22.265
Animal G (4)		26.633	25.929	0.419	–	–	23.873
Animal H (5)		27.193	26.336	0.450	0.006	0.310	22.983
Coefficient of digestibility of raw potatoes							
Animal H (1)		90.6	92.2	69.1	–	86.7	95.3
Animal E (2)		85.7	86.1	66.2	71.4	–	93.7
Animal F (3)		86.3	87.7	47.6	–	51.2	93.1
Animal G (4)		86.8	88.9	64.5	–	–	97.4
Animal H (5)		88.8	90.6	67.4	7.8	45.8	94.8
In feces of dried potato ration							
Animal H (2)	212.102	28.811	26.039	0.695	0.723	11.501	10.116
Animal E (4)	172.634	26.960	23.895	0.717	0.714	10.816	8.309
Animal F (1)	199.828	28.344	25.215	9.752	0.796	11.046	9.084
Animal G (3)	198.241	26.484	23.375	0.719	0.614	10.676	8.112

* Numbers in brackets refer to periods.

TABLE 14.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES—193[illegible]—Concluded

(Collection period of 12 days; weights in kilogrammes; [illegible])

—	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	[illegible]	[illegible]
Digested from dried potatoes							
Animal H (2)		27 701	26 585	0 342	–	–	24 548
Animal E (4)		30 025	28 814	0 369	0 005	–	26 389
Animal F (1)		28 347	27 480	0 322	–	–	25 534
Animal G (3)		30 719	29 586	0 332	0 127	0 555	26 676
Coefficient of digestibility of dried potatoes							
Animal H (2)		82 3	83 2	54 9	–	–	90 3
Animal E (4)		87 5	89 1	61 1	3 9	–	95 6
Animal F (1)		83 9	85 8	51 1	–	–	94 0
Animal G (3)		89 1	91 1	54 5	87 6	67 6	96 2
In feces of soaked dried potato ration							
Animal H (3)	210 117	27 786	24 780	0 730	0 672	10 984	8 980
Animal E (1)	176 410	2/ 868	24 894	0 748	0 705	10 947	9 004
Animal F (4)	236 887	27 821	24 546	0 816	0 729	11 062	8 335
Animal G (2)	187 829	27 831	24 903	0 705	0 693	10 670	9 365
Digested from soaked dried potatoes							
Animal H (3)		29 417	28 181	0 321	0 069	0 247	25 808
Animal E (1)		28 823	27 801	0 326	0 018	–	25 614
Animal F (4)		29 164	28 163	0 270	–	–	26 363
Animal G (2)		28 681	27 721	0 332	0 017	0 253	25 299
Coefficient of digestibility of soaked dried potatoes							
Animal H (3)		85 3	86 7	52 7	47 6	30 1	93 1
Animal E (1)		85 3	86 8	51 7	15 7	–	94 3
Animal F (4)		85 0	87 0	44 7	–	–	95 5
Animal G (2)		85 2	86 8	53 3	15 7	33 6	93 0

ANALYSIS OF SOIL FOR SEEDS

A METHOD OF CONCENTRATING THE SEEDS FROM SOIL FOR THE PURPOSE OF COUNTING AND NAMING THE SEEDS IN A SOIL SURVEY

F. C. DYER[1]

University of Toronto, Toronto, Ontario

[Received for publication February 18, 1938]

INTRODUCTION

In addition to the seeds in soil, there are pebbles, sand, and fine particles down to colloidal sizes, of inorganic origin derived from rock decay. This material constitutes the largest portion of the soil.

Mixed with this is a further portion of organic origin, consisting of vegetable matter from leaves, roots, and other plant remains more or less decayed, and varying in size of particle from chunks of wood down to humus of microscopic sizes. A small portion may be of animal remains such as snail eggs, casts of wood lice, small shells, etc.

If the soil is from a cultivated piece of ground there may be also particles derived from fertilizers, ash, fragments of brick and pottery, pieces of coke and such material.

The specific gravity of the particles ranges from 2 6 and over, down to about 1 5 for the inorganic matter and to less than 1 for some of the organic matter. Thus the soil consists of particles of a wide range of specific gravity and of size. The seeds are in the lighter portion.

From this mixture it is desired to concentrate the seeds into the smallest possible bulk in order to reduce the labour of sorting to a minimum, and to do this without destroying or so damaging the seeds as to make identification impossible.

METHODS

An outline of a method of concentration that has proved successful follows —

(1) Dampen the soil if necessary until the earthy parts are soft.

(2) Screen through a 4-mesh screen breaking the lumps if any.

(3) Wash the over-size clean. Only the very largest species of seeds will be retained on the screen and are easily picked out. This operation is to remove the larger pebbles that might damage the seeds in subsequent operations.

(4) Feed the material that passes the 4-mesh screen into a tumbling barrel with a considerable flow of water. The operation of the barrel disintegrates the soil and washes out the lighter portion that contains the seeds. Many of the seeds are heavier than water, but since the specific gravity of the seeds is not over 1 4 they will wash out with the mud due to the velocity of flow of the water through the disintegrator. The coarser sand remaining in the tumbling barrel is seed-free, except for possibly some of the very large seeds which if present are easily picked out when the barrel is emptied. The coarser sands may be discarded.

(5) The overflow from the mill is passed over a 100-mesh screen, the material that passes through the screen going to waste. From one-half

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[1] Associate Professor of Mining Engineering.

TABLE 14.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES—1937—*Concluded*

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)—*Concluded*

—	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
Digested from dried potatoes							
Animal H (2)		27.701	26.585	0.342	–	–	24.548
Animal E (4)		30.025	28.814	0.369	0.005	–	26.389
Animal F (1)		28.347	27.480	0.322	–	–	25.534
Animal G (3)		30.719	29.586	0.332	0.127	0.555	26.676
Coefficient of digestibility of dried potatoes							
Animal H (2)		82.3	83.2	54.9	–	–	90.3
Animal E (4)		87.5	89.1	61.1	3.9	–	95.6
Animal F (1)		83.9	85.8	51 1	–	–	94.0
Animal G (3)		89.1	91 1	54 5	87 6	67.6	96.2
In feces of soaked dried potato ration							
Animal H (3)	210.117	27.786	24 780	0 730	0.672	10 984	8.980
Animal E (1)	176.410	27 868	24.894	0.748	0.705	10.947	9 004
Animal F (4)	236.887	27 821	24 546	0.816	0.729	11.062	8 335
Animal G (2)	187.829	27.831	24.903	0.705	0.693	10.670	9.365
Digested from soaked dried potatoes							
Animal H (3)		29.417	28 181	0.321	0 069	0.247	25.808
Animal E (1)		28.823	27.801	0.326	0.018	–	25 614
Animal F (4)		29.164	28.163	0 270	–	–	26 363
Animal G (2)		28.681	27 721	0.332	0.017	0.253	25 299
Coefficient of digestibility of soaked dried potatoes							
Animal H (3)		85 3	86.7	52 7	47.6	30.1	93 1
Animal E (1)		85 3	86.8	51 7	15.7	–	94.3
Animal F (4)		85 0	87.0	44.7	–	–	95 5
Animal G (2)		85.2	86.8	53.3	15 7	33.6	93.0

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If the soil is from a cultivated piece of ground there may be also particles derived from fertilizers, ash, fragments of brick and pottery, pieces of coke and such material.

The specific gravity of the particles ranges from 2.6 and over, down to about 1.5 for the inorganic matter and to less than 1 for some of the organic matter. Thus the soil consists of particles of a wide range of specific gravity and of size. The seeds are in the lighter portion.

From this mixture it is desired to concentrate the seeds into the smallest possible bulk in order to reduce the labour of sorting to a minimum, and to do this without destroying or so damaging the seeds as to make identification impossible.

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An outline of a method of concentration that has proved successful follows:—

(1) Dampen the soil if necessary until the earthy parts are soft.

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(4) Feed the material that passes the 4-mesh screen into a tumbling barrel with a considerable flow of water. The operation of the barrel disintegrates the soil and washes out the lighter portion that contains the seeds. Many of the seeds are heavier than water, but since the specific gravity of the seeds is not over 1.4 they will wash out with the mud due to the velocity of flow of the water through the disintegrator. The coarser sand remaining in the tumbling barrel is seed-free, except for possibly some of the very large seeds which if present are easily picked out when the barrel is emptied. The coarser sands may be discarded.

(5) The overflow from the mill is passed over a 100-mesh screen, the material that passes through the screen going to waste. From one-half

[1] Associate Professor of Mining Engineering.

to two-thirds or more is eliminated at this stage. A 100-mesh screen is specified because with one or two rare exceptions all seeds are retained by a 100-mesh screen.

(6) The material remaining on the screen (and the sands remaining in the tumbling mill if so desired) are screened with a 10-mesh screen. The material remaining on the screen being coarse and free from mud is easily examined for seeds and can then be discarded. In some cases it may be possible to discard the sands from the mill after examination and without being screened through the 10-mesh screen, thus reducing the quantity to be treated later.

(7) The material through the 10-mesh screen is then washed on a reciprocating table of the Wilfley type, which eliminates all the heavier inorganic matter, the seeds being collected with the vegetable matter and some of the lighter inorganic substances.

(8) With a rich soil or one which has been fertilized with ash this last portion may be too large for convenient examination. A heavy liquid can be used to remove more of the vegetable matter and almost all of the remaining inorganic matter.

(9) The lighter fraction, now only a few ounces, may still be difficult to examine on account of the smallness of the particles. A further reduction in quantity may be made by passing the material through a set of differential rolls which will disintegrate the remaining humus without crushing the seeds.

(10) After passing through the rolls the material is screened through a 100-mesh screen to remove the fine humus.

(11) The remainder on the screen is then washed and dried for examination.

None of these processes takes very long; the whole operation can be completed in about three hours on a 15-pound sample of soil. Some steps of this operation may be eliminated for special cases such as the use of the washing table to remove sand from a swamp muck. Some soils consisting of loose fine sand might be fed directly to the washing table. As a whole, the method is applicable to practically every kind of soil that may contain seeds.

A QUANTITATIVE EXAMPLE OF A CONCENTRATION OF SEEDS

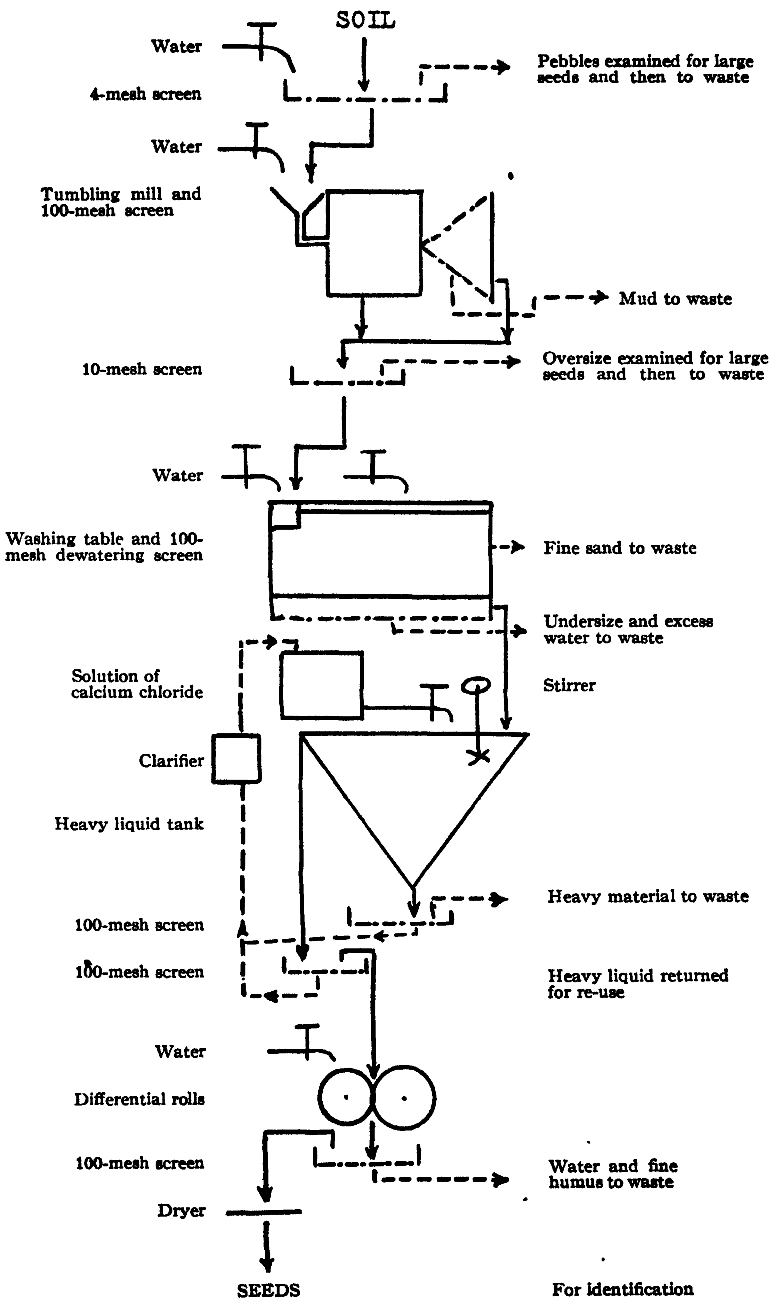
The material used in this test was a city garden soil which had been fertilized with household ashes and contained some of almost everything one could expect to find in soil (see Table 1). The soil as received was dry and in hard lumps.

TABLE 1

Materials	Weights
Original material (soil from a garden)	5840 grams = 100%
Pebbles separated on 4-mesh screen	None
Mud eliminated after disintegration	3808 grams = 65.0
Removed as +10-mesh material	253 grams = 4.3
Sand eliminated by the washing table	1036 grams = 17.7
*Eliminated by heavy liquid and rolls	736.4 grams = 12.6
Remaining seed concentrate	6.7 grams = 0.11

* This portion is unusually large because of the garden soil having been fertilized with ashes.

FLOW SHEET



The path of the seeds is shown by a solid line.

This complete flow sheet may be often simplified to suit particular soils by leaving out some of the steps of the process.

On careful examination the discarded portions showed a total absence of seeds. So that from an original weight of 12 lbs. 14 oz. the seeds were collected into a fraction weighing about ⅛ of an ounce.

NOTES ON THE OPERATIONS

Preliminary Wetting

The circumstance that the soil may be received in a hard dry condition is no detriment to the separation of the seeds. The dryness might possibly be an advantage in that the seeds being dry would be harder and more resistant to any possible though unlikely subsequent damage. Several sprouted seeds from damp soil have been seen to go through the above separation process and be caught and identified.

The disintegrator or tumbling barrel is a revolving horizontal cylinder about 12 inches in diameter and 12 or more inches long. One end should be easily removable for emptying the mill. At one end is an inlet pipe for soil and water and at the centre of the other end a larger pipe for outlet. The R.P.M. is about 60. A mill this size can take an initial charge of about 5 lbs., and considerably more can be added with the wash water as disintegration proceeds. With an ordinary soft soil the effluent water will run clear in about 20 minutes, depending on the size of the soil sample. The grinding in this mill is negligible so far as seeds are concerned. After half an hour's tumbling, small earthworms and minute shells have been found in the sand apparently unharmed. The seeds cannot be harmed by the tumbling in the mill for they are washed out of the mill by the running water as soon as they are liberated from the clots of soil.

The slime screen of 100-mesh wire cloth to remove most of the mud may be a conical screen attached to and revolving with the mill. Water from a spray pipe may be used to help to keep the screen clean. A stationary screen blinds too easily with the fibrous organic matter and would have to be very large to give satisfactory screening.

The washing table does not require to be large. An ordinary laboratory sized Wilfley table about 2 ft. × 3 ft. is large enough. It is advisable to extend the thin end of the riffles to the table end in order to hold the sand well up on the table. Enough water is used to wash the seeds and organic matter over the lower side of the table. Unless the quantity of sand to be washed on the table is very large, the sand etc. can be fed to the table by hand, or if the quantity is very large, an automatic feeder of the belt type might be added. Or it might be possible to allow the plus 100-mesh overflow from the tumbling barrel screen to pass directly to the washing table and eliminate the 10-mesh screen. It would then be necessary to watch that none of the larger seeds passed away with the sands discarded from the washing table. An advantage in retaining the 10-mesh screen preliminary to the washing table is that it conveniently removes twigs, leaves, grass roots, etc. that would be a difficulty on the washing table and later.

The washings of light material can be caught in a screen bottom trough attached to the edge of the table. The motion of the screen with the large quantity of water keeps the screen from blinding and also gets rid of the unwanted wash water.

The removal of the seed from the heavier sand is very complete. Several lots of this waste sand have been tested with heavy solutions and by germination tests without finding a seed. Sometimes there may be present light specific gravity mineral matter that is perforce washed out with the vegetable matter and goes along with the seed. This would be unusual with a field soil but might be expected in a city or market garden soil because of the use of ashes as fertilizer.

The Heavy Solution

To make the heavy liquid, a solution of crude calcium chloride is satisfactory. The material used was made by the Bruner Mond Company, Amherstburg, Ontario, for putting on the roads. It is not very hygroscopic and can be stored without difficulty in the original paper-lined jute bags. It dissolves in cold water to a clear solution after time has been given for the extremely small air bubbles produced to rise to the top. The solution will acquire some discoloration with use but can be used repeatedly. It is also cheap.

The Heavy Solution Separation

The seed-carrying material from the washing table can be collected by a water jet into a suitable container and the excess water removed. This may be by drainage, by centrifuging or partial drying. It is not necessary for the material to be completely dried, for the principal reason for removing the water is to avoid diluting the heavy solution used in the next separation. Calcium chloride in water makes a convenient heavy solution.

Repeated trials have shown that the seeds of the various kinds listed below can be floated by a liquid of 1.370 specific gravity. This density will float every seed tested and will allow to sink almost all of the mineral matter and a considerable amount of the organic matter.

The seeds actually tested were: Wheat; oats; timothy; red, sweet and alsike clovers; alfalfa; nightflowering catchfly; bladder campion; white cockle; foxtail; ribgrass; field peppergrass; flea seed; lambsquarters; dock; fleabane; pigweed; cinquefoil; panic grass; sedge; stitchwort; mustard, and artemesia.

The effect of the heavy calcium chloride solution on the specific gravity of the seeds is negligible even after several hours soaking of the seeds in the solution.

In introducing the material to the heavy solution it is advisable to use agitation to break up clots so that seeds will not be trapped in the settling sands and organic matter.

The loss of heavy solution is small, for only a comparatively small quantity of material is to be treated, because of the previous removal of most of the waste soil.

One advantage of using a heavy solution for removing the last part of the mineral matter from the seed-containing material is the readiness with which, by diluting the solution to obtain other solutions of lesser specific gravities, a separation of the heavier seeds from the lighter ones can be made, thus aiding identification of the seeds.

It would be possible to use a heavy solution applied to the whole sample of soil, but it is not advisable, for disintegration would still be

necessary. A considerable quantity of liquid would be required, which would rapidly become useless, because of the taking up of the mud, making the solution thick and because of the increased amount of organic matter collected with the seeds.

The Differential Rolls

After the heavy solution has removed all possible material there will probably be considerable organic matter still with the seeds. By using differential rolls, the soft vegetable matter may be easily reduced in size so that it will pass a 100-mesh screen without at the same time breaking up the seeds.

The set of rolls consists of two rollers of different diameters, say 3 inches and 4 inches diameter, and about 12 inches long. Each roll face is covered with a piece of sponge rubber about $\frac{3}{8}$ of an inch thick. The rolls are geared together and spaced to exert a slight pressure at the line of contact.

When the rolls turn, the face of the larger roll travels at a slightly faster rate than the face of the smaller roll, giving rise to a slight rubbing action in the material as it passes through. Two rolls of the same diameter and different R.P.M. will give the same result. The rolls can be kept clean either by a water spray on the larger roll or by letting one roll dip into water. In operation, the feed is smeared on one roll so that it passes through the set of rolls only one seed deep.

This rolling does no damage to the seeds. A quantity of seed mixed with vegetable matter and some sand was passed through such a set of rolls over and over again until the set of rolls had torn to pieces everything it could. After eight passes the numbers of seeds recovered were the same as were started with at the beginning.

In another test, some sprouting seeds were passed through these rolls without being destroyed.

The length of time during which the seeds are wet in the preceding processes is so short that no appreciable extra softening of the seeds takes place whereby the gentle friction of the rolls could damage the seeds. The final operation is simply washing on a 100-mesh screen to remove the calcium chloride and then drying the seed ready for identification.

Flotation, as an alternative method of separating the seeds from soil, is not as good as the above method, though it is known that seeds are gathered in the froth of a flotation machine. The extraction is not positive and definite; some seeds being quite difficult to float. Flotation will not eliminate the primary processes of disintegration and screening to remove coarse mineral particles. The seed-carrying froth usually will also pick up fine sand and humus and require additional treatment. If the flotation is done by the usual laboratory machines the quantity of soil that may be treated at one time is limited.

The processes previously described and outlined on the accompanying flow sheet may easily be applied to a large quantity of soil thus allowing of good sampling of the original ground. The method is flexible; does not call for skilled operators; with ordinary care it is not subject to loss of seeds, and leaves the seeds in good condition for identification.

INEXPENSIVE SOIL SAMPLE PULVERIZER

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[Received for publication May 16, 1938]

PURPOSE

Most rapid soil test methods require a dry, fine product free of hard lumps, roots and stones. To do this with a glass rolling pin and hand sieve is very laborious and slow. The machine designed and described is capable of pulverizing lumps of soil containing stones up to three-quarters of an inch diameter, and removing all undesirable material from the fine sample in approximately one minute. The final product may be adjusted to pass through the desired sieve.

The total cost of the machine, including the motor, was less than ten dollars. With good care and proper adjustment, the life of the machine should be many years and maintenance negligible.

DESCRIPTION

The essential part of the pulverizer is an old clothes wringer, turned on its side and driven at about 100 RPM by a $\frac{1}{4}$ H.P. electric motor. To prevent the rollers from stopping as a stone passes through, an 18″ cast iron fly-wheel is attached directly to the roller shaft. This fly-wheel acts as a pulley from the motor, driven by a 1″ rubber belt. The motor pulley is about 1.2″ diameter. The soil sample is fed to these rollers by a wooden hopper, tin lined, which is fastened directly above it, and feeds to about the centre half of the rollers, through a $1\frac{3}{4}$″ to 1″ slit. The rollers, being old and rough, grab the lumps.

Coarse stones, roots, etc. are removed below the rollers by a $\frac{3}{8}$″ screen, mounted on a light wooden frame, which may be very easily removed for cleaning. A second tin hopper collects the finer material which passes through the screen and directs it through the centre two-thirds of a second set of rollers. These rollers are newer and smooth. As the course material passes through, the soil lumps are broken up, while the stones sink into the rubber and pass through unchanged. The mixture is collected on the final screen, which is surrounded by a suitable rectangular tin guide, and fits tightly but easily over the tin tray. Only slight shaking is required to separate the sample from the waste. The sample is ready for testing.

MATERIALS USED

One used clothes wringer from a machine, the running parts being in good condition, but the rollers badly scarred; wood frame.

One clothes wringer, new or used; wood frame type, preferably from a washing machine, and in good condition, having smooth rollers.

One fly-wheel pulley of cast iron, about 18″ diameter × 3″ rim, taken from an old farm side rake.

[1] Student Assistant.

One motor—quarter horse-power, washing machine type, used but in good condition.

Belting—1″ × 6′ of flat rubber with steel lacing.

Tin—1 sheet 20″ × 30″.

Screens—1′ × 1′ of meshes 3 and 12.

Lumber—1 piece ½″ × ½″ × 7′ dressed pine for screen frames; 1 piece 1″ × 6″ × 6′ d.p. for motor bed and top hopper; 1 piece 1″ × 3″ × 7′ d.p. for framework and legs of machine; 1 piece 3″ × 3″ × 1′ for turning pulleys (maple).

FIGURE 1

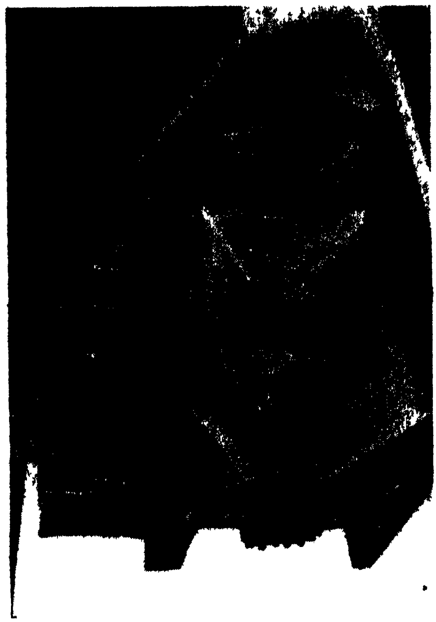
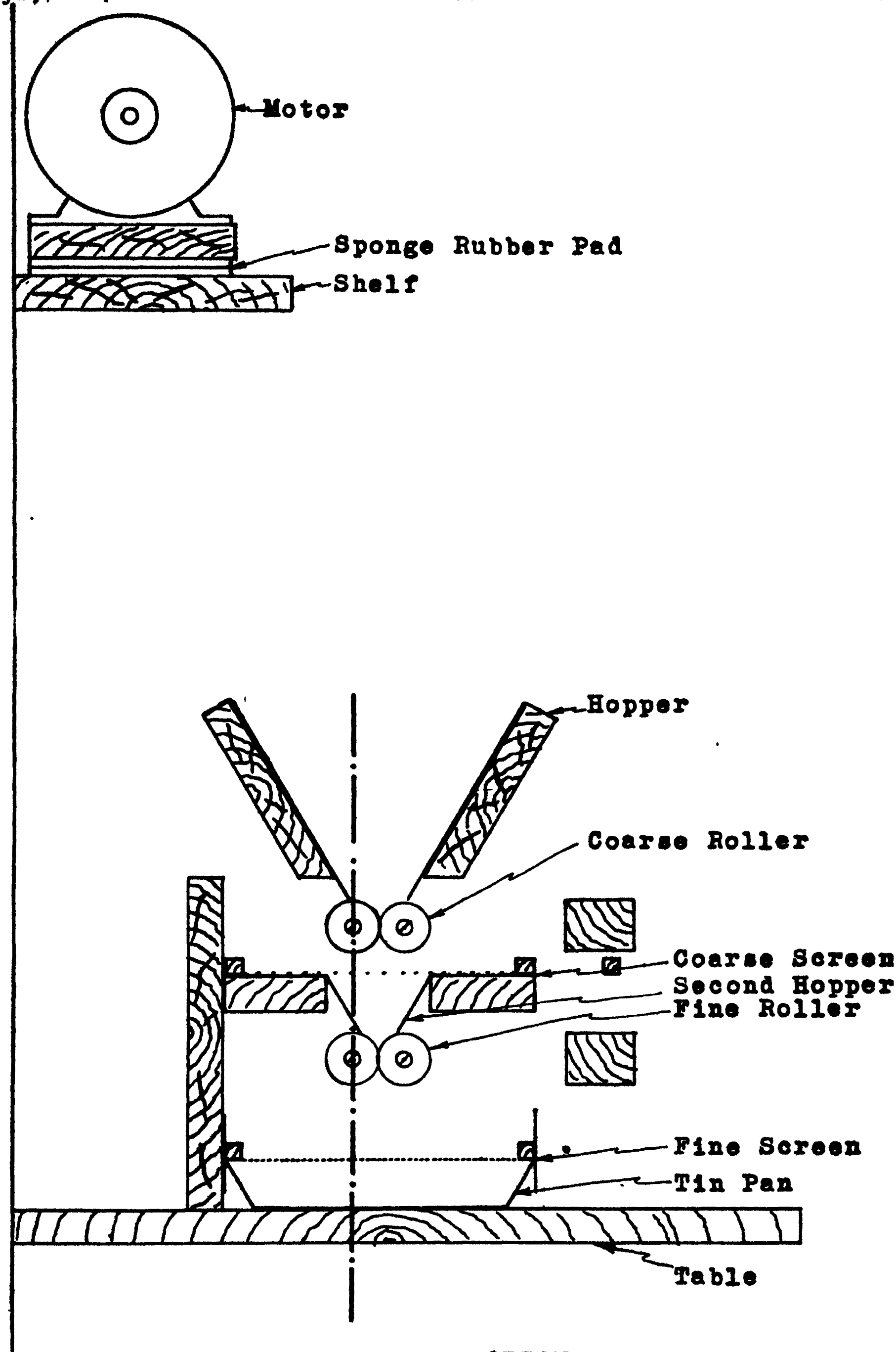


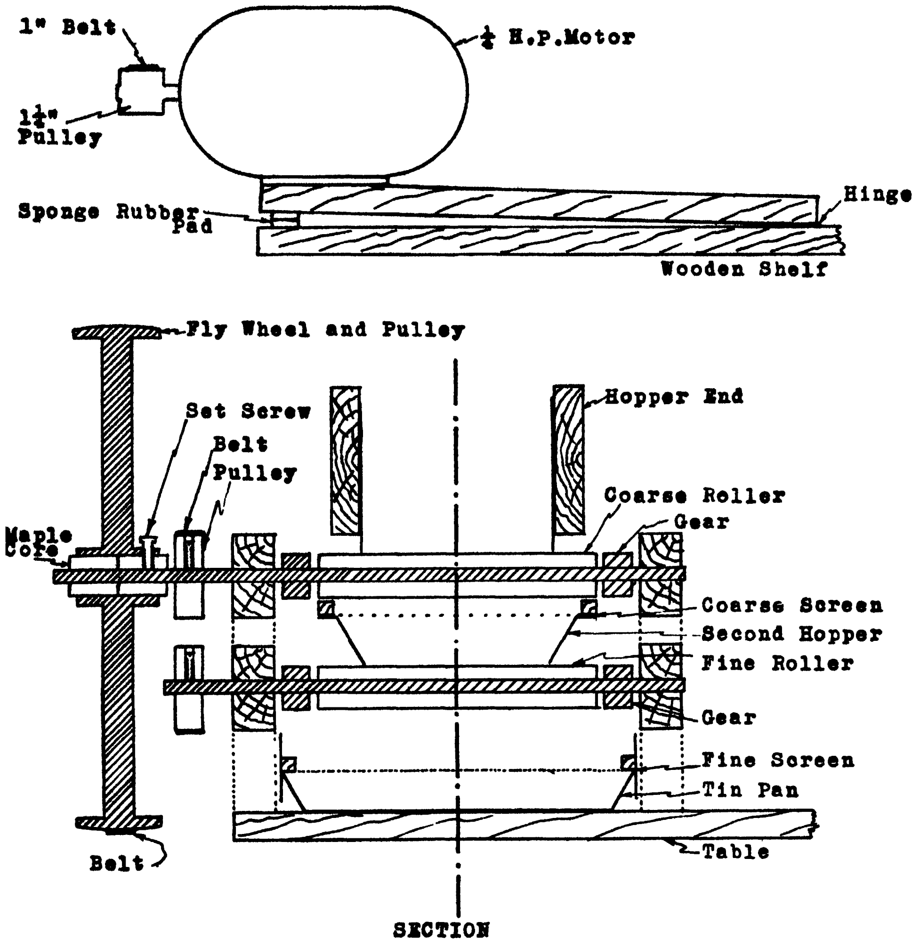
FIGURE 2

CONSTRUCTION

The pulleys were all made of maple. The motor pulley, 1½″ long and 1¼″ diameter was made by first boring the hole for the motor shaft, and then clamping the block on a grinding arbor and turning down to the desired diameter. The centre of the pulley should be made with slightly greater diameter than the edges. This tends to keep the belt on. The finished pulley was fastened to the motor shaft by means of a set screw countersunk into the wooden pulley. The motor shaft had a flattened key way. The pulleys for the roller drive were made exactly the same way and about 1½″ wide by 3″ diameter. They were fastened to the shaft by means of set screws also. The shafts were filed slightly flat on one side to receive these screws. The fly-wheel was found to have about a 1½″ hole through the hub. A maple plug, drilled for the shaft as before, was turned, in two sections of the proper diameter and driven into each end of the hub. The hub of the wheel was drilled and tapped (at the machine shop) to take



SOIL PULVERIZER
FIGURE 3



SOIL PULVERIZER

FIGURE 4

a ¼" × 2" bolt, as a set screw. Again the shaft was filed flat to receive the set screw.

The main feed hopper was made of rugged wooden construction, so that any large lumps of soil might be broken up to pass through the machine. This was just a simple V box with vertical ends and tin lining. The side pieces were extended the full length of the frame, for support. The end blocks were placed about 2" from each end of the rollers. The hopper was lined with sheet tin, so that soil would not stick to it. The slot in the bottom of the hopper was about 1½" wide and 8" long and was placed as close to the rollers as possible. A second hopper of tin was built in, just above the second rollers to direct the soil into them. This was about 3" wide at the top, 1" wide at the bottom and 10" long at the top and 8" long at the bottom.

The wringers were stripped of all undesirable parts, such as the water directing boards and excess driving mechanism. The small pulleys were fastened onto the shafts and the wringers were ready for assembly. Two strips of wood, 1″ × 3″ were fastened to the top of the fine roller set (when horizontal). These supported the second hopper and extended the full length of the frame, lending rigidity. They were also bolted directly to the top roller set, which was placed on top. Four legs of 1″ × 3″ pine were now cut so as to leave about 3″ below the second rollers. These legs were firmly fastened to each side and to the back, by means of screws, into both coarse and fine roller frames. The total height of the machine is about 12″ without the hopper. The main feed hopper was then securely fastened in position by means of nails or screws into the ends of the coarse roller frame. Care was taken in placing all screws so as to leave the pressure adjustment free.

The top screen was tacked to a ½″ × ½″ wooden frame made to slide in just under the coarse rollers. The frame of the screen rested across the two 1″ × 3″ boards joining the frames of the rollers. The frame for the bottom screen was made to fit over the tin receiving pan. Tin strips, 2″ high, extended above and below the frame, forming a box, with a screen bottom and tin sides, which, when placed on the pan, fitted under the second fine rollers to collect the pulverized sample.

The motor was mounted on a shelf *above* the machine. This is very desirable since the motor bearings, which are of bronze, thus support part of the weight of the fly-wheel, which would cause excessive wear on the wooden wringer bearings and soon cause belt slipping and undesirable replacement and trouble. The motor was placed on pegs at the end of the 1″ × 6″ × 2′ board, which was hinged at the other end, as shown in the diagram, to the shelf. The board on which the motor stands is supported on the shelf by a pad (adjustable) of several layers of sponge rubber. This absorbs noise and vibration and provides a means of tightening the belt.

OPERATION

Due to the momentum of the flywheel and the method of drive, it is necessary to spin the wheel by hand, at the same time closing the switch, when starting the machine. However, with steady operation it is only necessary to do this occasionally and it is not inconvenient after a little practice.

Adjustment must be made for various types of soil, some requiring higher pressure to break them up. The pressure should be kept as low as possible, however, since this causes less strain on the machine. From time to time the belts tend to slip. The small belt may be tightened by wrapping a few turns of friction tape about one or both pulleys. This may be also used for the motor pulley. The long belt may also be tightened by increasing the sponge rubber pad under the motor.

Lubrication of all the bearings, including the motor, should be carried out about every hour of operation. This is very necessary since the soil dust soon causes rapid wear.

Feeding the sample is very simple after the machine has been properly adjusted. The sample may be just dumped into the hopper. Any large

lumps are easily broken up with a screw driver or other tool. As soon as the sample has all passed through the coarse rollers, the coarse screen is shaken vigorously, a few times. The material easily passes into the second rollers and is caught on the fine screen. The fine screen and pan assembly is removed and shaken vigorously until no more passes through. The coarse material on the screen is discarded and the sample in the pan may be further mixed by pouring back into the sample bag or box through a suitable funnel. The coarse screen need only be emptied after about 30 samples, or every half hour usually, but oftener if necessary. A small electric fan will carry all the dust away from the operator.

CONCLUSION

Over six hundred samples of soil, including both top and sub soils, were pulverized in the machine in an average of about one minute each. This saving in time alone would soon pay for the machine. With good care and proper adjustment, the time lost in breakdowns was almost negligible.

The design of mechanically shaken screens has been considered, but was soon discarded, since it is desirable to keep the machine as simple and as trouble-free as possible. A cover for the fine screen, to keep down the dust, has also been considered, but would mean another step in the operation, and would prove a nuisance.

The machine is a worthwhile addition to any soil laboratory, and should be a boon to rapid soil testing. It removes the drudgery and speeds the work of testing samples.

NUMBER OF SPECIES AS EVIDENCE OF PASTURE IMPROVEMENT[1]

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[Received for publication February 13, 1938]

To secure the best quantitative botanical data in connection with pasture improvement investigations, careful and rather tedious quadrat readings are ordinarily relied upon. When, however, botanical surveys were sought in 1928 as a part of the Dominion Experimental Farms' study of continuous *versus* rotational grazing along with fertilizer applications, the best that could be offered immediately, in view of the time involved, was a simple reconnaissance listing of the species present. Such listings, notwithstanding other technique added later, have been continued each year at the 6 eastern stations concerned, for periods varying from 5 years at Charlottetown, P.E.I., to 10 years at Fredericton, N.B. The present paper proposes to examine what value, other than qualitative, was to be had from this minimum outlay of time. It leaves for another occasion all elaboration of the subject which might be based on developments from this original procedure.

Briefly stated, the procedure was to record the names of all species, useful or otherwise, in about the order in which they were detected in the course of zigzag progress from end to end of the field, omitting no part which might vary from the general character of the vegetation. Roughly the same time was allowed for each field of like area, about 7 or 8 minutes for an acre usually. Closely grazed pastures, requiring closer attention to vegetative characters for grass identification, claimed more time.

Obviously, even such a list of plants present in a field has more than qualitative value, for the order of listing is a distinct reflection of the abundance of the species. Those dominant are promptly recorded, while others present sparingly could only by chance secure as high a list position. A series of such lists from a check field presumably undergoing little change, would give a close approximation to an order of abundance which for important species could readily be given rough percentage value by means of visual estimate. Such order of abundance, as well as such estimate, might indeed come closer to bulk or production reality than is often obtained by either count or ground cover data. Only experience is advanced here in support of this position, which is supplementary only to the main contention under review.

Surveys could not be made at any uniform date from year to year, nor more than once annually at most stations. Nearly all were made during the months of June, July and August, and it is found that lists were about equal in length from any part of that period, although slightly shorter in June. Spring and fall lists may be expected to lack certain of the short-season plants, and to be somewhat shorter.

Lists from different stations that are spread across a thousand miles or so from east to west, and vary in climate, soil and otherwise, may be

[1] Contribution No. 541 from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada.
[2] Botanist.

expected to vary in their species content. Different species, in part, and a different number of them are found at each point. The number is believed to be somewhat greater on the poorer and more acid soils, but it is clearly greater on the less stabilized pastures. The fields at Lennoxville and Ste. Anne were newly seeded for the experiment, and will be seen in the accompanying table to have lengthy lists of species; the fields at Ottawa and Nappan are old pastures, and give the shortest lists. The longer lists following tillage and re-seeding include, besides species introduced in the seed mixture, many weeds of arable land, mostly annuals, which tend to disappear as the land is compacted again, as well as the true pasture weeds, only temporarily checked by the breaking up of the previous turf. The short lists for old pastures, on the other hand, represent the survivors of a more or less drawn-out process of stabilization. Restriction of this study to one type from among these pastures would have some advantages, but to get the greatest possible volume of data they are all admitted, and the results from one type or all prove to be closely comparable.

NUMBER OF SPECIES IN SURVEY LISTS, 1928–1937, AVERAGED

—	Ottawa 1929–36	Lennoxvile 1930–37	Ste. Anne de la Pocatiere 1930–37	Fredericton 1928–37	Nappan 1929–37	Charlotte town 1929–34	Ave. of six stations	—
Continuous grazing fertilized	17.5	43 0	42 0	34.2	22 4	34 2	32 2	Ave. of 57 lists
Continuous grazing unfertilized	20.7	52.3	41.6	48 4	31.7	39 0	39 5	Ave. of 52 lists
Rotational grazing fertilized	17.7	42.3	36.0	34.0	24 1	35 2	31.5	Ave. of 50X lists

In this table the two differentials of the experiment may be compared for each of the 6 stations, and for all stations together. It should be explained that each figure for rotational grazing is the average of 3 fields, or at Fredericton 4 fields except when occasionally fewer fields were taken as representative of those rotated. Also at Lennoxville separation of the two factors of the experiment provided an extra field continuously grazed and needing to be surveyed.

It will be seen from the average of the 6 stations that lists contain slightly fewer species with rotational than with continuous grazing, and distinctly the most without fertilizer. Observation, yield plots and animal gains are agreed in ascribing most improvement in these pastures to application of fertilizer, and to factors other than rotational grazing. Indeed, there has never been entire agreement among these various stations that rotational grazing materially helped. It is therefore of interest to note in which direction, though ever so slightly, this quite impersonal evidence points. It is shown, in any case, that application of fertilizer is followed by reduction of species in a pasture.

Evidence from phases of the surveys outside our present scope is ample to show that this reduction of species is of weedy species largely. Any exact distinction between weedy and useful species remains, however,

a matter of personal opinion, and is not here attempted. We may reasonably assume that the increase and invigoration of cultivated and other plants requiring the higher fertility levels is at the expense of weeds largely, which are opportunists present while the plant food, moisture and space are not fully pre-empted. Some weeds, like couch grass, dandelion, buttercup and plantain, are plants of rather high fertility levels, and being also strongly rooted, they persist well, but they are rather exceptions to the rule. The shallow-rooting hawkweeds and ox-eye daisy, the low growing species which are smothered by the thickening of the cover, and the annuals of arable land which survive for only a short time after seeding, are the majority whose wane and elimination with fertilizing is thus recorded. Some of the reduction of species, it is true, is to be attributed to the loss of sown grasses and legumes not fully winter-hardy, or, like red clover of short duration if prevented by grazing from reseeding, but such loss should be as great, if not greater, on the unfertilized fields.

It is not in the least the purpose to advance any new technique in place of current methods of securing ecological or grassland data, but it has seemed desirable to demonstrate that even the simplest reconnaissance listings, often the only surveys that time will allow, are capable of giving valuable information over a period of years. Such listings in sufficient numbers also give frequency indices which, though not equivalent to abundance, are indicative of it. Finally, visual estimates of percentage cover by each important species. add only a little more to the time required, and under the practised eye of the same observer from year to year, can secure a large part of the primary appraisal desired.

A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS*, HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

V. THE SEASONAL CHARACTERISTICS OF FLIGHT, OVIPOSITION AND LARVAL ESTABLISHMENT. THE VARIATIONS AND EFFECTS OF SEASONAL CLIMATE. THE FACTORS CAUSING FLUCTUATIONS IN BORER POPULATIONS. SUMMARY. ACKNOWLEDGMENTS

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[Received for publication, January 12, 1938]

Previously, the flight, oviposition and establishment periods have been dealt with as individual subjects. It is now proposed to consider the periods as seasonal entities; to show the part each plays in regulating the borer population and to discuss the physical factors affecting them as weather.

Review of the Literature

The literature concerning the abundance of the borer and its control by natural factors deals largely with yearly cycles and not with any particular season or insect stage, although Barber and Babcock have, as noted below, carried out researches on the effect of weather on egg laying and on the pupal period, respectively.

Barber (2) claimed that the cool nights of the year 1923 decreased the abundance of the borer in the New England area because the moths did not lay as many eggs as usual. The longer egg-laying season also increased egg parasitism.

Caffrey (4) gives a brief discussion of the climate experienced by the borer in its European habitats and compares the climates with those of certain American localities to which the borer may spread. No conclusion is reached, and flight, oviposition and establishment periods are not mentioned.

Babcock (1), upon whose work Caffrey's statements summarized above were made, discusses seasonal history in relation to various climates. He emphasizes the importance of the necessity of free moisture at the time of pupation. Flight, oviposition and establishment periods are not dealt with.

Thompson and Parker (10) consider the newly hatched corn borer larva a very delicate mechanism with highly restricted adaptive powers. Even in the most favoured environment and in the normal course of events, larvae undergo considerable mortality at the time of establishment. This apparently inherent weakness they term an intrinsic controlling factor. They point out that such factors are operative for other insects as well, and are probably far more important than realized in maintaining a natural equilibrium in insect species. Larval mortality, they state, varies under different conditions and is nearly always more important than that resulting

[1] Entomologist in charge.

from all other factors combined. They state that meteorological factors such as excessive heat or cold, extreme drought, drenching rains, or violent winds, if they occur at critical periods such as at the moment when young larvae are hatching or during periods of oviposition or during pupal period, may and undoubtedly do, cause a more or less heavy mortality, but unfortunately, little is known as to the part they play in the control of the borer.

Caesar (3) concluded from general observations and some experimental work that a very hot, dry season, especially in July and early August, is very unfavourable to the borer because of the mortality it causes among the newly hatched larvae. Hot, dry seasons also lessen the length of life of the adult, and hence the number of eggs. He concluded that between 1927 and 1930, in Ontario, the weather as a whole was unfavourable to the borer. Weather is so great a factor in control that in spite of the best practical clean-up of corn refuse, the borer may increase with ideal weather.

The seasonal variation in the number of eggs laid in 1929 and 1930 as observed by Flint (8) has already been discussed in part IV.

Caffrey and Worthley (5) determined that the percentage survival of larvae in 1931 was twice that of the drought year 1930. The next year the same authors (6) say that during 1930 a combination of deficient precipitation and excessively high temperatures during critical periods of the season were more adverse to the insect than for any season during the past 29 years. They point out that among the principal factors affecting the abundance in 1932 in Eastern United States were the more favourable weather for oviposition, a high larval survival and a large borer survival in corn refuse in the spring.

Davis (7) claims that the borer has not increased greatly in northern Indiana during the last 8 years because of unfavourable climatic conditions during the egg-laying and incubation periods, although other factors also may have been acting. He states that the years 1930, 1933 and 1934 were definitely unfavourable to the borer, 1932 not entirely favourable, and 1931 was favourable. His conception of dry, hot winds peeling egg masses from leaves has already been noted. According to Vance (11), the year 1936 was also unfavourable in Indiana and the borer population decreased.

Vance (11) attributes the decrease in the borer in eastern Indiana and the "thumb" section of Michigan in 1936 to the effect of lack of rainfall in the first half of July, supplemented by abnormally high temperatures prevalent during the second week of July.

In northwestern Ohio and southwestern Michigan, an increase in borer population occurred with a more favourable moisture distribution. This permitted an increase despite a pupal mortality of approximately 20% caused by excessive heat during the second week in July.

THE SEASONAL VARIATION IN MOTH POPULATION, REPRODUCTION AND SURVIVAL AT CHATHAM, ONTARIO.

Table 1 brings together for the first time data which have been presented during the progress of the paper. In this table the egg survival on plants is based on the number of eggs left on the plants after the mortality from dislodgement had taken place. Total egg survival is based upon the

total number of eggs laid. Larval survival is based upon the number of larvae hatching from eggs left after egg mortality had taken place, while total survival is based upon the total number of eggs laid.

TABLE 1.—THE SEASONAL VARIATIONS IN MOTH POPULATION, REPRODUCTION, SURVIVAL AND POPULATION INDEX, CHATHAM, ONTARIO, 1927 to 1936

Year	Total no. females in flight	No. eggs laid per female per 100 plants	Percentage egg survival			Percentage larval survival	Percentage total survival	Population index
			From dislodgement	On plants	Total			
1927	1431	4.9	—	—	—	—	—	—
1928	607	2.5	99.0	96.3	95.2	43.8	41.7	632
1929	104	7.6	93.4	98.0	91.4	18.1	16.5	130
1930	156	9.0	96.1	94.0	90.2	7.6	4.6	64
1931	66	5.1	97.4	92.3	89.8	57.2	51.4	173
1932	166	9.6	73.5	92.4	67.8	24.8	16.8	267
1933	224	6.8	88.3	94.4	83.2	21.1	17.6	271
1934	24	12.9	66.0	100.0	65.9	28.1	18.6	57
1935	23	15.2	86.4	91.9	79.2	48 7	38.6	134
1936	94	11.8	97.6	88.4	86 1	30 5	26.3	291
Average	289.5	8.5	88.7	94.2	83.2	27.9	23.9	224

The year 1928, with its high population index, was the most favourable for borer development, while 1934, with its very low population index was the worst year for borer development.

Population Index

The population index as used in this paper is a term devised to describe the resultant borer population secured from the measurement of seasonal female moth population, egg production, and total survival. It is really the number of larvae surviving from the total number of eggs laid on 100 plants by the female population of the season.

It may be expressed mathematically by the expression,

$$PI = (A \times B)C$$

Where PI = population index, A = the number of females in flight during the season, B = the number of eggs laid per female per 100 plants per season and C = the percentage of total survival. Total survival is the number of larvae, in percentage, surviving from the total number of eggs laid. It includes both egg and larval mortality.

Population index shows the result at the end of the season of adult and larval activity. The effect of all biotic and physical factors on the adult, egg and larval stage has taken place and their influence has modified the population index. The more favourable the season to borer development and increase, the higher will be the population index. The fluctuations in the magnitude of the population index will be shown later to have a very close correlation with the variations in the field population over wide areas, as expressed by percentage of stalk infestation.

It has been shown in Table 1 that some years have been definitely more favourable than others to the development of the corn borer. The table also shows for the various years at what point in the seasonal history of the insect the reduction or increase has taken place, whether it has been low moth population, low egg production, high egg mortality, either from dislodgement or in eggs remaining upon the plants, or because of high larval mortality.

Correlation of Borer Activity and Climatic Factors within Five-day Periods

To study the effects of the various physical factors on flight, oviposition and establishment, it is necessary to determine the time of the season these activities take place and then to evaluate the effect of the factors influencing them at the critical time. Seasonal occurrence and variations have been determined accurately and discussed at some length.

To study the effect of seasonal climate and the climate affecting definite periods, the season of flight, oviposition and establishment has been divided into eight, 5-day periods for each year. The percentage of the seasonal total of moths in flight, of eggs laid and of larvae hatching and other characteristics pertaining to the borer, are shown for each period in Tables 2 to 10. The average temperature, saturation deficiency, the number of rain showers and total rain are also indicated for each period.

The measurements of the physical factors were taken at the edge of the plots and constitute the records of a microclimate. Both temperature and saturation deficiency are based upon 12 bi-hourly readings for each 24 hours or 60 readings for the 5-day period.

TABLE 2.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, CHATHAM, ONTARIO, *1928*

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	—	—	0.0	0.0	0.0	0.0	0.0
2	July 5–9	74.2	5.88	1.	0.33	3.7	4.0	0.0
3	July 10–14	66.9	4.05	3.	1.60	10.3	15.5	1.4
4	July 15–19	73.6	6.21	3.	0.18	41.5	44.6	11.3
5	July 20–24	73.3	4.55	3.	2.41	30.6	27.9	29.0
6	July 25–29	66.8	4.36	2.	0.07	6.5	6.5	42.7
7	July 30–Aug. 3	73.1	6.05	2.	0.11	5.4	0.0	12.9
8	Aug. 4–8	75.1	5.11	1.	0.53	0.4	1.1	0.0
Total				15.	5.23			

Total number of female moths in flight	607
Length of flight period in days	32
Number of eggs per female per 100 plants	2.5
Average number of eggs per mass	15.1
Per cent egg survival from dislodgement	99.0
Per cent egg survival on plants	96.3
Per cent total egg survival	95.2
Per cent larval survival	43.8
Per cent total survival	41.7
Population index	632

TABLE 3.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON 1929, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	66.1	5.82	3	0.57	0.9	*28.9	0.0
2	July 5–9	72.2	5.89	2	0.68	29.6	—	0.0
3	July 10–14	69.0	6.20	2	1.31	15.7	—	1.6
4	July 15–19	65.7	7.79	0	0.0	21.2	15.9	6.3
5	July 20–24	68.6	7.96	1	0.07	15.7	44.5	31.5
6	July 25–29	77.1	8 60	2	1.66	13.8	8.3	51.1
7	July 30–Aug. 3	68.2	7.53	0	0.0	2.7	2.2	6.2
8	Aug. 4–8	64.5	6.59	0	0.0	0.0	0.0	2.7
Total				10	4.29			

Total number female moths in flight	104
Length of flight period in days	28
Number of eggs laid per female per 100 plants	7 6
Average number of eggs per mass	14.6
Per cent egg survival from dislodgement	93.4
Per cent egg survival on plants	98.0
Per cent total egg survival	91.4
Per cent larval survival	18.1
Per cent total survival	16.5
Population index	130

* 28 9% of eggs were laid during periods 1–3, inclusive.

TABLE 4.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1930, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	—	—	2	0 16	13.0	12.4	2.6
2	July 5–9	70.1	6.59	1	0.02	57.3	32.8	7.1
3	July 10–14	66.1	5 74	2	0.20	19 5	28.9	46.6
4	July 15–19	71.1	10.63	0	0.0	8.2	2.8	36.2
5	July 20–24	73 6	8.00	2	1.15	1.1	7.4	4.2
6	July 25–29	74.9	8.20	1	0.03	0	0	2.5
7	July 30–Aug. 3	73.0	10.69	0	0.0	0	0	0
8	Aug. 4–8	75.7	9.82	1	0.01	0	0	0
Total				9	1.57			

Total number female moths in flight	156
Length of flight period in days	26
Number of eggs laid per female per 100 plants	9.0
Average number of eggs per mass	16.6
Per cent egg survival from dislodgement	96.1
Per cent egg survival on plants	94.0
Per cent total egg survival	90.2
Per cent larval survival	7.6
Per cent total survival	4.6
Population index	64

TABLE 5.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1931, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	79.4	9.01	0	0	12.5	11.0	0
2	July 5–9	72.0	7.07	2	1.50	31.9	30.0	0
3	July 10–14	69.6	7.57	0	0	34.7	14.1	34.8
4	July 15–19	76.4	6.53	1	0.85	20.8	13.2	7.7
5	July 20–24	70.6	5.58	3	0.81	0	21.6	22.0
6	July 25–29	77.6	9.56	1	T.	0	9.7	24.1
7	July 30–Aug. 3	73.7	7.31	0	0	0	0	10.8
8	Aug. 4–8	77.5	8.94	0	0	0	0	0
Total				7	3.16			

Total number female moths in flight	66
Length of flight period in days	20
Number of eggs laid per female per 100 plants	5.1
Average number of eggs per mass	12.7
Per cent egg survival from dislodgement	97.4
Per cent egg survival on plants	92.3
Per cent total egg survival	89.8
Per cent larval survival	57.2
Per cent total survival	51.4
Population index	173

TABLE 6.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1932, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	66.8	6 73	3	0.89	0.5	4.1	0
2	July 5–9	67.7	5.35	1	0.35	34.1	17.4	4.0
3	July 10–14	70.5	6 13	2	1.20	36.2	31.0	6.4
4	July 15–19	77.3	6.44	0	0.00	17.8	30.4	13.6
5	July 20–24	72.2	5.74	1	0.53	5.6	1.1	57.7
6	July 25–29	68.7	4.28	3	1.40	0	7.5	7.6
7	July 30–Aug. 3	71.1	5.79	1	0.35	0	1.9	1.7
8	Aug. 4–8	71.5	6.77	3	0.58	0	0	8.4
Total				14	5.30			

Total number female moths in flight	166
Length of flight period in days	26
Number of eggs laid per female per 100 plants	9.6
Average number of eggs per mass	16.8
Per cent egg survival from dislodgement	73.5 (83.4)
Per cent egg survival on plants	92.4
Per cent total egg survival	67.8 (77.7)
Per cent larval survival	24.8
Per cent total survival	16.8 (19.2)
Population index	267

TABLE 7.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1933, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
-	June 20–24	70.5	9.28	2	0.22	10.0	0	0
-	June 25–29	78.6	10.02	1	0 03	30.3	52.4	0
1	June 30–July 4	69.8	6.46	2	0.99	23.2	26.0	30.3
2	July 5–9	71.4	8.26	2	0.54	27.4	13.3	48.3
3	July 10–14	69.1	8.12	0	0.00	12.4	0	11.9
4	July 15–19	69.3	7.30	1	0.24	5.3	3.4	1.6
5	July 20–24	76.1	8.15	3	1.05	0.2	1.3	1.6
6	July 25–29	71.5	8.64	0	0.00	0	2.4	2.0
7	July 30–Aug. 3	75.3	8.95	1	2 00	0	0	2.5
8	Aug. 4–8	66.9	6.38	1	0.09	0	0	0
Totals				10 (13)	5.16 (4.91 in 8 periods)			

Total number female moths in flight	224
Length of flight period in days	27
Number of eggs laid per female per 100 plants	6.8
Average number of eggs per mass	15.1
Per cent egg survival from dislodgement	88.3
Per cent egg survival on plants	94.4
Per cent total egg survival	83.2
Per cent larval survival	21.1
Per cent total survival	17 6
Population index	271

TABLE 8.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1934, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	74 9	11 51	0	0 0	29 2	11.8	0
2	July 5–9	69 8	5.93	3	0.37	17.0	11.8	0
3	July 10–14	75 5	6 58	3	0.47	29 2	44.4	25.7
4	July 15–19	71 8	8.63	1	0.08	17 0	31 8	14.6
5	July 20–24	78 7	11.81	1	0 03	4.8	0	59.5
6	July 25–29	72 4	8.87	1	0.38	0	0	0
7	July 30–Aug. 3	68 5	5.93	2	1.03	0	0	0
8	Aug. 4–8	69 5	6.93	1	1.17	0	0	0
Totals				12	3.53			

Total number female moths in flight	24
Length of flight period in days	25
Number of eggs laid per female per 100 plants	12.9
Average number of eggs per mass	17.9
Per cent egg survival from dislodgement	66.0
Per cent egg survival on plants	100.0
Per cent total egg survival	65.9
Per cent larval survival	28.1
Per cent total survival	18.6
Population index	57

TABLE 9.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1935, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	72.2	6.01	0	0.0	0	0	0
2	July 5–9	74.7	5.61	3	0.18	10.3	0	0
3	July 10–14	76.5	8.63	0	0.0	44.8	33.3	0
4	July 15–19	70.7	6.22	2	0.78	37.9	22.1	7.2
5	July 20–24	77.0	5.26	3	0.33	6.8	31.2	42.6
6	July 25–29	71.3	6.05	1	0.22	0	4.8	33.5
7	July 30–Aug. 3	75.1	6.71	1	0.34	0	8.9	6.3
8	Aug. 4–8	72.4	5.01	3	0.86	0	0	10.0
Total				13	2.71			

Total number female moths in flight	23
Length of flight period in days	18
Number of eggs per female per 100 plants	15.2
Average number of eggs per mass	15.4
Per cent egg survival from dislodgement	86.4
Per cent egg survival on plants	91.9
Per cent total egg survival	79.2
Per cent larval survival	48.7
Per cent total survival	38.6
Population index	134

TABLE 10.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1936, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	62.6	4.65	2	0.67	5.3	7.2	0
2	July 5–9	74.6	10 80	0	0	37.4	27.1	7.9
3	July 10–14	84.1	14.25	0	0	39.6	38.1	26.8
4	July 15–19	70.0	10 15	0	0	12.9	27.5	52.0
5	July 20–24	65.9	7.26	1	0.47	3.8	0	6.6
6	July 25–29	67.5	7.26	1	0.44	0	0	5.8
7	July 30–Aug. 3	67.7	8.87	0	0	0	0	0
8	Aug. 4–8	65.6	7.05	0	0	0	0	0
Total				4	1.58			

Total number female moths in flight	94
Length of flight period in days	27
Number of eggs per female per 100 plants	11.8
Average number of eggs per mass	15.5
Per cent egg survival from dislodgement	97.6
Per cent egg survival on plants	88.4
Per cent total egg survival	86.1
Per cent larval survival	30.5
Per cent total survival	26.3
Population index	291

A climatograph of the microclimate is given for each year in Figures 1 and 2. In the climatograph the average temperature is plotted against the average saturation deficiency for each period. The numbered points on the climatographs, instead of representing months as in an ordinary climatograph of a yearly climate, represent each 5-day period, the numbers and dates of which are shown on the tables. Rainfall is shown only in the tables.

The climatographs show the general character of each season and are directly comparable as to dates of each period. The variation in dates at which each insect stage is present is shown in the tables.

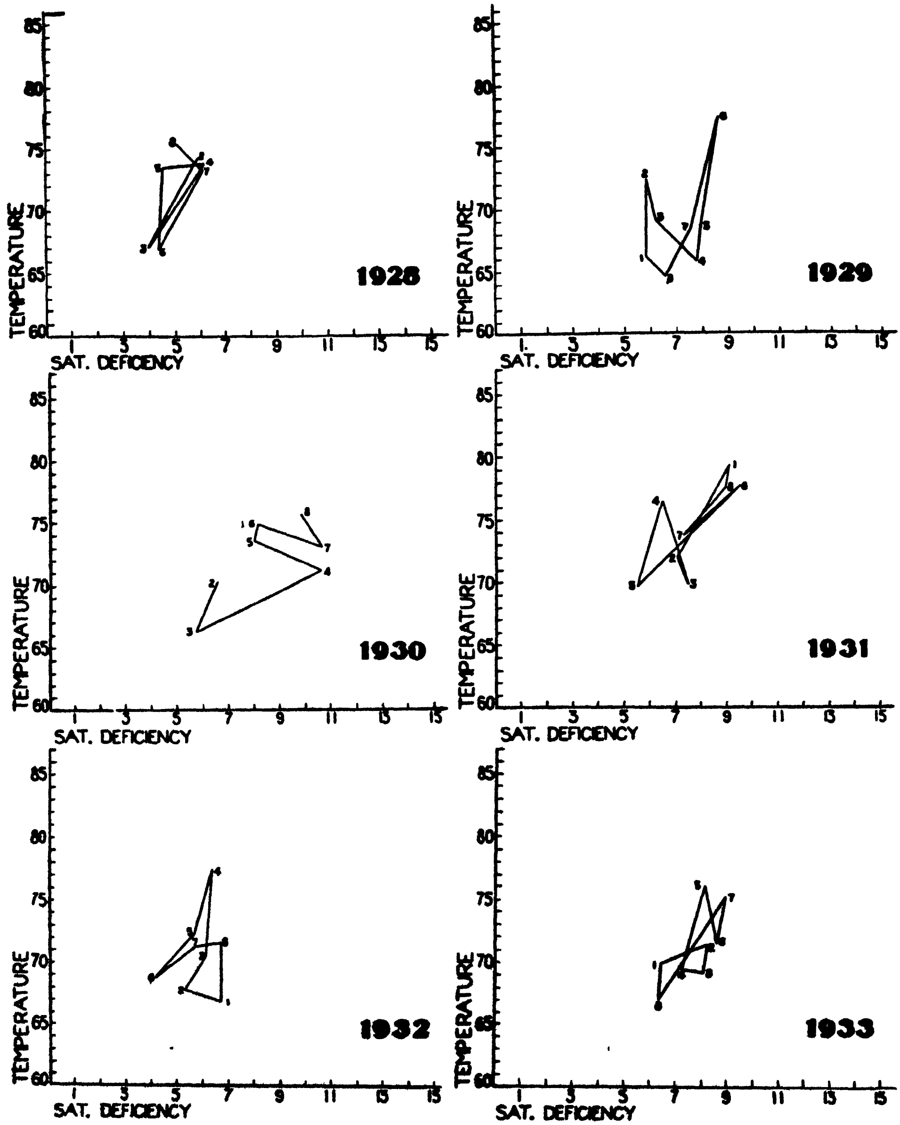

Figure 1. Climatograph of microclimate of plots for season of flight, oviposition and establishment, 1928 to 1933, Chatham, Ontario.

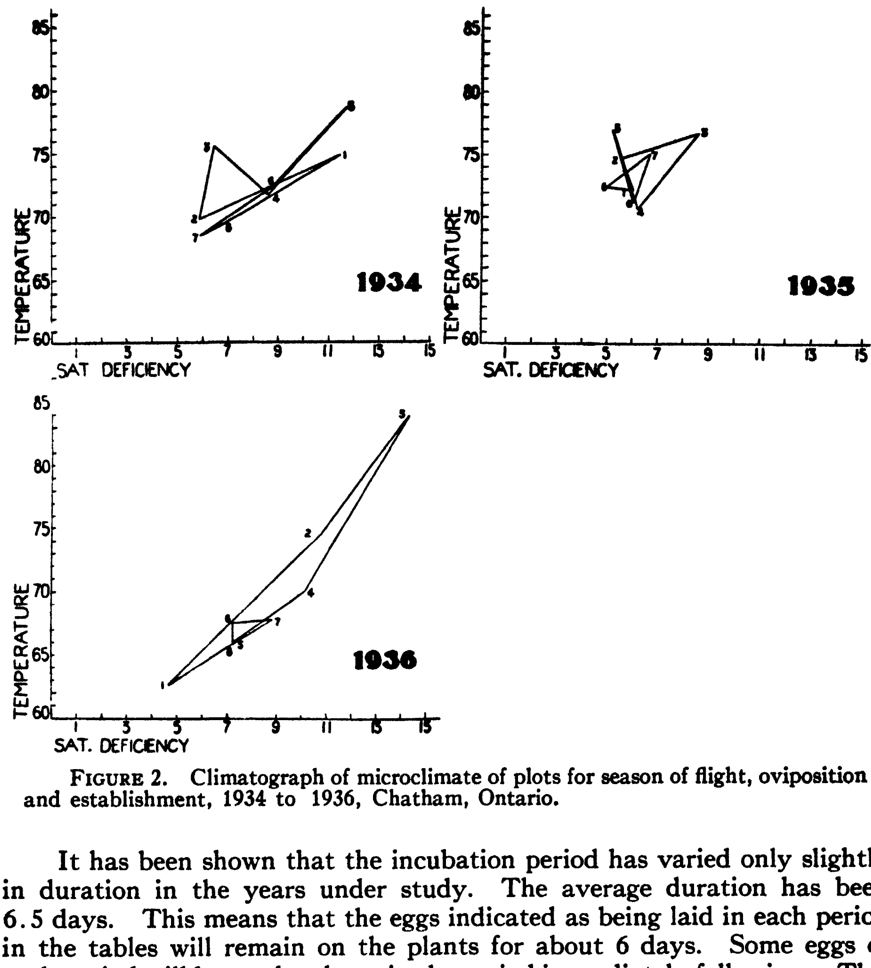

FIGURE 2. Climatograph of microclimate of plots for season of flight, oviposition and establishment, 1934 to 1936, Chatham, Ontario.

It has been shown that the incubation period has varied only slightly in duration in the years under study. The average duration has been 6.5 days. This means that the eggs indicated as being laid in each period in the tables will remain on the plants for about 6 days. Some eggs of each period will be on the plants in the period immediately following. This extension of the eggs into the next period has to be understood when determining the effect of weather upon them.

It has been shown, from a review of the literature, that larval mortality takes place immediately after hatching and within a period represented by the first 2 instars. The first 2 or 3 days after hatching determines the fate of the larvae. Any factors influencing their mortality will do so largely within the period in which they are known to have hatched. These periods are indicated in the tables.

Seasonal Characteristics of Moth Population, and Egg and Larval Survival

The most favourable year for borer development was 1928 because of the large initial moth population and the high egg and larval survival. It was the poorest year, of any, for egg laying. The flight period was the longest of any year, although about 70% of the moths flew in the two periods numbered 4 and 5. Egg laying was also largely confined to these periods, but most of the eggs hatched in periods 5 and 6. Periods 4 and 5

have an average temperature of about 74° F., with high humidity. Period 6 was much colder with about the same humidity.

Although 1928 was the best year for borer development of those studied, it was not the best year in the history of the borer in the region. This will be discussed later under population index and field infestations.

The year 1929 was below average in favourableness to the borer. This was largely because of the small numbers of moths in flight, but also because of the lowered total survival which was less than half that of the previous year. The lessened survival was largely confined to larval survival. The number of eggs per female increased about 5%.

The year 1930 had an available moth population of about one-quarter that of 1928 and about one-third more than that of 1929. Each female laid about 4 times as many eggs as in 1928 and about 2% more than in 1929. Egg survival was reduced about 5% from that of 1928 and about 1% from that of 1929. Larval survival was the lowest for any year, while total survival was also the lowest for any year, being only 4 6%. In spite of an increased moth population and more eggs per female the high larval mortality made 1930 a very unfavourable year for the borer. With its low survival, this year would have needed an initial population of about 1500 moths to give it the same population index as in 1928. The year 1930 was definitely unfavourable to the borer throughout western Ontario and a large section of the north central states. Caffrey (6) has already been quoted as saying the climate of this year was the most unfavourable of any in the last 29 years.

The year 1931 was below average in favourableness to the borer. The moth population was about one-ninth of that in 1928 and less than half of the population of 1930. Each female laid about twice as many eggs as in 1928, but only a little less than one-half of those laid by each female in 1930. Egg survival was about 5% lower than in 1928 and about the same as in 1930. Larval survival was the highest of any year, being 13% higher than in 1928 and 49 6% higher than in 1930. Caffrey (5) as already noted, says that in the northeastern United States survival was twice that of 1930. In our case, the survival was 10 times that of 1930.

The year 1932 had a moth population of a little less than one-fourth that of 1928 and about two and one-half times the number of 1931. Four times more eggs were laid per female than in 1928 and about double the number of 1931. Egg survival was low, being 27% below that of 1928, and 22% below that of 1931. The low egg survival was due largely to a local hail storm as already discussed. Larval survival was 21% lower than in 1928 and 32% lower than in 1931. The increase in the number of adults and increased egg production made 1932 above average in favourableness in spite of a marked decrease in egg and larval survival.

The year 1933 was slightly more favourable to borer development than was 1932. The moth population was slightly more than one-third of that of 1928 and increased about one-third over that of 1932. Each female laid a little less than 3 times as many eggs as in 1928, but only about one-third as many as in 1932. Egg survival was about 12% less than in 1928, but 15% more than in 1932. Larval survival was 22% less than in 1928, but only about 3% less than in 1932. The increase in the number

of adults present during this year was offset by the fewer number of eggs per moth and a decrease in larval survival.

The year 1934 was characterized by having a moth population one-twenty-fifth that of 1928 and only one-tenth that of 1933. Each female, however, laid 5 times as many eggs as in 1928 and about twice as many as in 1933. Egg survival was 29% less than in 1928 and 17% less than in 1933.

Egg mortality was confined to the egg masses being dislodged from the plants. Larval survival was 15% less than in 1928 and 7% more than in 1933. The low moth population, the poor egg survival and less than average larval survival made this the poorest year of any for the borer.

The year 1935 had a moth population of about one-twenty-fifth that of 1928 and practically the same population as in 1934. Each female laid 6 times as many eggs as in 1928 and approximately 3% more than in 1934. Egg survival was 24% less than in 1928 and 13% more than in 1934. Larval survival was 5% more than in 1928 and 20% more than in 1934. With the same moth population as in 1933, but with an increased egg production per female and an increase of 20% in survival, this year was over twice as favourable to the borer as was the year 1934.

The year 1936 had a moth population of a little more than one-sixth of that of 1928, but 4 times that of 1935. Each female laid about 5 times as many eggs as in 1928, but about 3% less than in 1935. Egg survival was 9% less than in 1928, but about 7% more than in 1935. Larval survival was 13% less than in 1928, and 18% less than in 1935. The greater moth population made it a better year for the borer in spite of an 18% decrease in larval survival.

Summary of Seasonal Characteristics

The variations in borer development in each year have been described and compared directly with the year 1928, which was the best year for development under study, and with the year previous. These variations will now be summarized.

A decrease in the borer population in 1929 was brought about largely because of a decrease in the available moth population, but also because of a very low larval survival.

Further reduction in population was brought about in 1930 by an extremely low larval survival. The moth population available for flight was larger than in the previous year.

An increase in population occurred in 1931 because of the extremely high larval survival. High survival caused an increase in population in spite of a greatly lowered moth population.

An increase in population occurred in 1932 because of a larger moth population and an increased number of eggs laid per female. These two factors overcame an adverse, low larval survival.

Population was increased in 1933 because of a larger available moth population when the survival was just a little below average.

A marked reduction in population occurred in 1934 because of a great reduction in moth population and a high egg mortality from dislodgement. This was the worst year of the 9 for borer development.

The borer population increased in 1935 because of greater egg production, a high egg survival and a high larval survival, while the moth population remained at the same level as in 1934.

The borer population increased in 1936 because of the greater moth population and to some extent the larger number of eggs laid per female. Egg and larval survival remained about average.

Biotic Factors Causing Seasonal Variation in Borer Population

It will be seen that the main biotic factors causing an increase or decrease in population in the summer season of flight, oviposition and establishment have been (A) the available moth population, (B) the larval survival, (C) the egg production per female and (D) the egg mortality.

Table 11 shows the biotic factor or factors responsible for a variation in the population during the years under study.

TABLE 11.—MAIN BIOTIC FACTORS CAUSING VARIATIONS IN BORER POPULATIONS FOR EACH YEAR, CHATHAM, ONTARIO, 1928-36

Year	Type of variation in population	Biotic factors causing variation
1929	Decrease	Moth population and larval survival
1930	Decrease	Larval survival
1931	Increase	Larval survival
1932	Increase	Moth population, egg production
1933	Increase	Moth population
1934	Decrease	Moth population, egg survival
1935	Increase	Egg production, larval survival
1936	Increase	Moth population

Moth population alone has been a deciding factor for 2 years in the increase or decrease in population. Moth population in combination with other biotic factors has been the deciding factor 3 other years. Larval survival alone has been the deciding factor in 2 years, while in combination with other factors it has been the deciding factor in 2 other years. Egg survival has been a factor in combination with moth population in 1 year. Egg production per female in combination with other factors has been the deciding factor in 2 years.

The important varying biotic factors in the summer season are available moth population and rate of larval survival or establishment. The physical factors affecting these will be discussed later.

Classification of Years According to Favourableness to Borer

As previously noted, and as shown in Table 1, the year 1928 was the most favourable year for borer development studied. As will be shown later, it appears that none of the years studied have been, on the whole,

entirely favourable to borer development. The years under study, however, have varied in their favourableness and may be classified.

TABLE 12.—A CLASSIFICATION OF YEARS ACCORDING TO FAVOURABLENESS TO BORER DEVELOPMENT, CHATHAM, ONTARIO, 1928–1936

Favourable year	Above average in favourableness	Below average in favourableness	Very unfavourable
1928	1932	1929	1930
	1933	1931	1934
	1936	1935	

This classification is somewhat similar to that of Davis (7), supplemented by Vance (11), who show that in northern Indiana the years 1930, 1933, 1934 and 1936, were definitely unfavourable, 1932 was not entirely favourable, and that 1931 was favourable to borer development. The years 1933 and 1936 were more favourable in Ontario than they were in northern Indiana, while 1931 was possibly less favourable than in that region.

THE PHYSICAL FACTORS (CLIMATE) AFFECTING EGG AND LARVAL MORTALITY AND EGG PRODUCTION

Egg Mortality and Survival from Dislodgement

Survival from dislodgement has been uniformly high with an average survival for the 9 years of 88.7%. It was lowest in the year 1932 and 1934. These and other seasonal variations are shown in Table 1.

It has been shown previously that mortality from dislodgement in 1932 was due to a local hail storm.

The dislodgement of egg masses in 1934 will be discussed. In this year, egg production, because of the few moths in flight, was very low. In spite of the low egg production the year was peculiar on account of the high egg mortality from dislodgement. This was not only the case at Chatham, but it also occurred in other regions. Davis (7) as already pointed out, definitely noted that eggs were dislodged at a high rate during this year in northern Indiana.

Table 8 shows that 88% of the total eggs of the season were laid in periods 2, 3 and 4; 45% in period 3. The average weather conditions for these periods are shown graphically in Figure 2.

The dates on which egg masses were dislodged from plants during this year and for all other years have been shown previously. Two egg masses fell from the plants on July 13, 1934. This would indicate that conditions just previous to this date were conducive to the loosening of egg masses. This would be in period 3 on the climatograph, Figure 2, and in Table 8. This period shows an average temperature of 75.5° F.,

and a saturation deficiency of 6.58 mm., and three rain showers with 0.47 inches of rain. These average figures are not unlike other periods noted in which egg masses were not dislodged from the plants.

A more detailed survey of the weather, beginning on July 8, shows a series of hot days with cold nights as illustrated below:

Date	Maximum temperature	Minimum temperature
July 8	80	53
July 9	81	52
July 10	85	53
July 11	87	71
July 12	90	64
July 13	90	62

The humidity during the period was quite high as shown by the average saturation deficiency of 6.2 mm. It was not a hot, dry period.

The year 1934 is the only year of the 9 in which a period of hot days and very cold nights occurred during the time eggs were on the plants. This condition must have caused, directly or indirectly, the high egg mortality from dislodgement which took place in this year.

This conclusion is supported by the fact that a similar period of hot days and cool nights occurred in norther Indiana during 1934 when a high mortality, through dislodgement of egg masses, was noted by Ficht and Davis. G. A. Ficht of the Purdue Agricultural Experiment Station, has kindly supplied the weather records taken by him, in the field, at Auburn, Indiana, during the years 1932 to 1936. The year 1934 is the only one in which a period of hot days and cold nights occurred during the time egg masses were on the plants in numbers. The similarity of the period to that experienced at Chatham can be seen from the following maximum and minimum temperatures for certain dates at Auburn, Indiana:

Date	Maximum temperature	Minimum temperature
July 4	84	55
July 5	92	74
July 6	94	64
July 7	76	54
July 8	81	50
July 9	83	53
July 10	88	55
July 11	90	64

In other years at Auburn, Indiana, the lowest temperature recorded in any year was 60° F., and generally the minimum temperature was above this temperature. Here then, is an unusual period of hot days and cold nights occurring only in the year 1934 and at two widely separated localities. In both localities the year was noted for egg mortality from dislodgement.

The type of period just described would be one in which the leaves of the corn plants would be wilted during the daytime, but turgid at night. There would be considerable movement in the leaves of plants undergoing these changes. Huber (9) has already suggested such movements may have considerable influence in the dislodgement of egg masses. The type of period just described would also be conducive to the production of moisture on the surface of the leaves by guttation. The cool nights would retard evaporation from the leaves, but the soil, being warm, would favour absorption of water by the plant. The comparatively high humidity of the year would also reduce evaporation from the leaves. This effect would be quite marked as the humidity in this particular year was higher than in similar hot periods during other years.

There were no particularly heavy winds or heavy rain storms during the period the eggs were on the plants which could have caused a greater dislodgement of eggs during this year in comparison to that of other years.

It is suggested that the type of weather existing in 1934 between July 8 and July 13 caused egg masses to be dislodged from the leaves. The weather is characterized by cold nights and hot days, with comparatively high humidity. Such a season is conducive to the daily wilting of corn plants. The movements of the leaves during the process of wilting and in regaining turgor when combined with the production of abundant moisture through guttation are thought to be connected in some manner with the loosening of the egg masses from the plants, probably due to the physical forces operative in the process of wilting and again in regaining the turgor of foliage.

Mortality and Survival of Eggs Remaining upon the Plants

The survival of eggs remaining upon the plants has been relatively high in all years studied. The uniformity of the survival affords little opportunity to study the effects of varying weather conditions upon the mortality.

Effect of the Physical Factors upon Number of Eggs Laid per Female

The prohibitive and regulatory influence of temperature upon the flight of moths has been discussed in Part III and the effect directly upon the number of eggs laid per female per night has been discussed in Part IV. It was shown that the individual night temperature had no effect upon the number of eggs laid but that night temperatures considered as a season had a great effect. It is now proposed to discuss the effect of the seasonal temperatures acting for the entire daily period over the entire season.

The exact season in which moths were in flight has been shown in Tables 2 to 10. In Table 13 the average temperature and saturation deficiency, the number of rain showers and total rainfall are given for the period of the season when moths were active. From Table 13 it can be seen that the lowest number of eggs per female were laid during 1928.

TABLE 13.—THE RELATIONSHIP BETWEEN SEASONAL WEATHER DURING THE FLIGHT SEASON AND EGG PRODUCTION PER FEMALE, CHATHAM, ONTARIO, 1928–1936

Year	Average temp.	Average sat. def.	Rainfall		No. eggs laid per female per 100 plants per season	Length of flight period in days
			No. showers	Total rain, inches		
1928	71	5.3	9	3.92	2.5	32
1929	72	7.2	5	2.06	7.6	28
1930	69	7.5	5	0.38	9.0	26
1931	72	7.0	3	2.35	5.1	20
1932	72	5.9	3	1.55	9.6	26
1933	72	8.1	7	1.78	6.8	27
1934	73	8.1	7	0.92	12.9	25
1935	74	6.8	5	0.96	15.2	18
1936	76	11.8	0	0.00	11.8	27

This year was characterized by a low average temperature, the highest humidity of any year, the greatest number of showers, and the largest total rainfall of any year. As shown previously, this was a favourable year for borer development in every particular, except egg laying. A reference to Table 2 will show that the first portion of the egg laying season was particularly cool with an average temperature of 66.9° F. This was followed by a warmer period with an average temperature of 73.3° F. which, in turn, was followed by another cool period with an average temperature of 66.8° F. Humidity was high throughout the year. These low temperature periods lowered the egg production of the females in much the same manner as in the case reported by Barber (2) when low temperatures reduced the egg production of moths in New England in 1923.

It has been indicated in Part IV that the best years for egg production were 1934, 1935 and 1936. These years were the warmest and driest during the egg-laying period.

There is a slight indication that the conditions existing in 1935 during the flight of the moths approached the optimum conditions for egg laying. A decrease in egg production took place in 1936 when higher temperatures and a greater drying power of the atmosphere were experienced. A marked decrease also took place in egg production in 1934, with a lowering of the average temperature and an increase in the saturation deficiency.

From these studies it appears that the best season for egg laying is one in which the average temperature is about 74° F. and the saturation deficiency about 7 mm. Rain showers should be frequent, but light.

Eggs per female are reduced when the average temperature is 71° F., and the saturation deficiency about 5 mm., and when the rainfall is frequent and heavy.

Effect of the Physical Factors upon the Length of Flight Season

From Table 13, it may be seen that there does not appear to be a relationship between length of flight season and seasonal temperature and humidity. The year 1928 which had a low temperature and the lowest saturation deficiency of any year also had the longest flight season. The year 1927, as indicated in Part II, also had a long flight season of 31 days. This year also was cool and moist and quite similar in this respect to 1928. A comparison between the two years may be made by referring to Figures 2 and 3, in Part III. The hottest and driest years experienced, namely, 1934, 1935 and 1936, had flight seasons of about average length.

There is no indication that moths were killed by excessive heat or the excessive drying power of the atmosphere. This type of mortality has frequently been suggested, in the literature, as a factor in the natural control of the borer, but it apparently does not take place under natural conditions. If moths were killed, one would expect a shortening of the flight season in the driest and hottest years, but no such shortening of the season has occurred. Moths must have lived as long as usual during the hot year of 1934, as during it, large numbers of pupae were killed early in the season, thus reducing the supply of moths. The flight in this year was not shortened and the small number of moths originally available lived as long as usual.

Effect of the Physical Factors (Climate) upon Larval Mortality and Survival

The best opportunity to demonstrate the effect of the physical factors upon larval survival was to study the years in which extremes of mortality and survival occurred.

The year most favourable to larval survival was 1931. In this year, 57.2% of the larvae hatching were able to establish themselves and mature. Table 5 shows that 35% of the larvae hatched during period 3 between July 10 and July 14, while 46% hatched in periods 5 and 6, between July 20 and July 29. There were 2 principal hatching periods during the season. The first period as shown on the graph in Figure 1, was characterized by an average temperature of 69.6° F., and a saturation deficiency of 7.57 mm., and was rainless.

The second hatching period, in periods 5 and 6, was characterized by average temperatures of 70.6° and 77.6° F. respectively and average saturation deficiencies of 5.58 mm., and 9.56 mm., respectively. Four light rains occurred with a total rainfall of 0.81 inches.

The highest daily maximum temperatures occurring in the periods or between them, were on July 17 and July 29. On July 17, the temperature reached 91° F., with a saturation deficiency of 15.64 mm. The highest temperature on July 29 was 95° F. with a saturation deficiency of 22.26 mm. The rise to these high temperatures was quite gradual as is shown by the mean daily temperatures for each day between July 11 and July 17. These are as follows:— 67° F., 66° F., 69° F., 72° F., 73° F., 76° F., 78° F. A similar gradual rise occurred to the peak of July 29 during the second hatching period. To summarize: the period was characterized by a divided hatching season; temperatures were comparatively high during both periods, but the peaks in temperature were attained by a gradual rise in daily mean temperatures; humidity was neither high nor low, but was about average, showing a saturation deficiency of between 5 mm., and 9 mm.; no rains occurred in the first hatching period, but 4 light rains fell during the second period totalling 0.81 inches.

The year 1935 was also favourable for larval establishment as 48.7% of the larvae survived. The biotic and climatic characteristics of the year may be seen from Table 9 and Figure 2. Seventy-six per cent of the larvae hatched in periods 5 and 6 between July 20 and 29. These periods had an average temperature of 77° F., and 71.3° F. respectively. The humidity was a little higher than average, the saturation deficiency being 5.26 mm., and 6.05 mm., respectively. Four rain showers occurred, giving a total of 0.55 inches of rain. The highest daily temperature experienced was 89° F., with a saturation deficiency of only 16.07 mm. No very great fluctuations in temperatures occurred during the periods. It was a comparatively uniform warm period, with humidity above the average level.

The year having the highest larval mortality and therefore the lowest survival was 1930. In this year, only 7.6% of the larvae survived. The biotic and climatic characteristics of the year are shown in Table 4 and in Figure 1. About 83% of the larvae hatched in periods 3 and 4, between July 10 and July 19. Period 3 was characterized by a low average temperature of 66.1° F., and a fairly high humidity; while period 4 had a higher but still low average temperature of 71.1° F. and a fairly low humid-

ity as shown by the average saturation deficiency of 10.63 mm. The drying power of the air was twice as great in the last period as it was in the first.

The hatching season was characterized by a comparatively cool, moist period, suddenly turning into a hot, dry period. This is shown by the average daily temperatures between July 10 and July 19, and which follow: 68° F., 69° F., 66° F., 70° F., 56° F., 58° F., 64° F., 73° F., 80° F., 80° F. The lowest actual temperature was 44° F., with a saturation deficiency of 1.48 mm., which occurred on July 14. The highest actual temperature occurred on July 18 when the maximum was 94° F., with a saturation deficiency of 31.06 mm. Two light rains, totalling 0.20 inches, occurred during period 3, but there was no rain during period 4.

The sudden hot spell or heat wave is reflected in the night temperatures charted for moth flight studies shown in Figure 5, Part III.

If high temperatures and low humidities, either alone or in combination cause larval mortality, by far the greatest mortality should have occurred in the year 1936 as this was the hottest and driest year on record during the time larvae were hatching. The larval survival for the year was 30.5% which is above the average survival for the 9 years.

The biotic and climatic characteristics of 1936 are given in Table 10 and in Figure 2. In this year, 80% of the larvae hatched in periods 3 and 4, or between the dates of July 10 and July 19. Period 3 is characterized by an average temperature of 84.1° F., and an average saturation deficiency of 14.25 mm. The atmosphere under these conditions was not only on the average, much warmer than during the previous years discussed, but its drying power was greatly increased, being twice as great as in 1931, over twice as great as in 1935, and considerably increased over that of the period 2 in 1930 when so many of the larvae were destroyed. The very high average temperature and high saturation deficiency of period 3 is shown strikingly in the climatograph in Figure 2. Period 4 was characterized by an average temperature of 70° F., and a saturation deficiency of 10.15 mm. There was no rain during either period.

There was a period of consistently high temperatures and low humidities until near the middle of period 4 when the temperature dropped. This decrease in temperature, however, came too late to influence survival as the larvae were already established. Temperatures as high as 102° F. with a saturation deficiency of 30.10 mm. were experienced during the heat wave.

From the above observations, it is concluded that variations in larval mortality and survival are brought about mainly by the destruction of larvae by very sudden changes in temperature. In 1930, the annual average survival of 27.9% was reduced to a survival of only 7.6% by a sudden heat wave during the season of hatching. The very hot, dry season of 1936 did not affect larval survival, and in the comparatively cool, high humidity year of 1928 the survival was much greater than usual. Sudden variations in temperature, even if at a comparatively high humidity, caused larval mortality. This conception has never before been advanced. Most authors deal with the subject in a general manner and attribute larval mortality to a number of factors, but mainly to hot, dry periods, or to winds or rains throughout the entire season.

The detrimental effect of rain upon larval establishment is overestimated in the literature. During the year 1931, in which larval establishment was highest, the hatching larvae were subjected to 4 rain storms. In 1935, the year in which the second highest survival took place, 4 rain storms were experienced during hatching. In 1928, the year in which the third highest rate of survival was found, there were 13 rain storms during the entire season, 5 of them taking place during the establishment period. In period 5, when 29% of the larval population hatched, the rain amounted to 2.41 inches within 4 days. In spite of this large amount of rain, larval survival was 43.8%. Rain storms do not influence larval survival to any appreciable extent.

Population Index and Field Infestations

The seasonal variations in borer populations obtained by plot study, and shown by the population index, bear considerable relationship to variations in field populations in wide areas. This relationship is shown in Table 14.

The population index for the years 1925, 1926 and 1927 is theoretical and based upon the following data. For the years 1925 and 1926 the total number of eggs laid per 100 plants per season as found by Ficht and presented in Part IV, is divided by the average number of eggs laid per female as found during the years 1927 to 1936 to determine the number of females in flight. The population index is then determined by the method evolved and presented previously, using the necessary average values as determined during the years 1927 to 1936 and presented in Table 1. In 1927, the moth population and eggs per female have been measured and presented. For this year, the average percentage of total survival as found during 1928 to 1936 was used for the calculation of the population index.

TABLE 14.—POPULATION INDEX AND FIELD INFESTATION IN KENT COUNTY AND IN HUSKING CORN REGION OF SOUTHERN ONTARIO, 1924–1936

Year	Population index	Per cent stalk infestation Kent county	Per cent stalk infestation husking corn area
1924	—	24	18
1925	*6927	53	31
1926	*7076	79	65
1927	*1682	47	49
1928	632	38	33
1929	130	26	30
1930	64	21	16
1931	173	27	22
1932	267	27	24
1933	271	35	29
1934	57	8	8
1935	134	24	22
1936	291	20	24

* The population index for these years is a theoretical value calculated as described in text.

The husking corn area, as used in the table, is constituted by the counties of Essex, Kent and Lambton. The stalk infestation for this area is much lower than for Kent county alone during the year 1924 and 1925 because Essex and Lambton counties were not yet fully infested or, if infested, the borer population was still quite low.

The percentage of stalk infestation has been compiled from records taken by the Provincial Entomologist of the Ontario Department of

Agriculture, and the Entomological Branch of the Dominion Department of Agriculture. The records are based upon determinations made on 300 stalks in each of, at least 40 fields per county in each year.

It is seen from Table 14 that, with the exceptions of the years 1932 and 1936 in Kent county, an increase or decrease in the population index foretells an increase or decrease in the field population in large areas. Even in 1932 and 1936 in the larger area, the trend is shown.

Population index does not show the rate of variations in the larger areas, but it does show population trend in each year.

Factors Causing Fluctuations in Field Populations

From the fact that field study plots located in the centre of Kent county, show the trend of borer population in wide areas, it may be adduced that the factors causing the variations are acting over wide areas and whole districts instead of being limited to small areas. It has just been shown by plot study that temperature, when in the form of sudden heat waves, causes high larval mortality, and that alternating very cold nights and hot days cause the egg masses to be dislodged from the plants. It has also been shown that rains have little or no effect on larval survival. These conclusions seem to be verified by the close relationship between study plots and field infestation, as temperature and, perhaps, humidity conditions are usually more uniform over large areas than are either rainfall or wind.

The factors responsible for the increase or decrease in borer population for the years 1929 to 1936 have been enumerated and discussed above. Although outside of the province of the present paper, something might be added regarding the decreases in population in the years 1927 to 1928.

The importance of initial moth population has already been shown and the importance of pupal mortality in this connection has been discussed in Part II. It has been shown that in the year 1934, a high pupal mortality occurred because a hot, dry period killed the pupae just before emergence. It is almost certain that pupal mortality is partly responsible for the large reductions in borer populations during the years 1927 and 1928. A very close and detailed survey of weather records reveals the fact that these years are the only ones, other than 1934, which experienced a similar hot, dry period during the time pupae were in the fields in numbers.

There was a comparable period in 1925, but it occurred between July 10 and July 15, which would be too late for pupae as they would have emerged by these dates. In 1926, there was a hot period of three days between July 8 and July 10 which was accompanied by rain. The hot, dry period of 1927 took place between June 28 and July 3. The average daily temperatures ranged from 68° F., to 84° F. with no rain between June 21, and July 2.

In 1928, the period was longer, extending from July 2 to July 11. The average daily temperatures ranged from 71.5° F. to 80.5° F. There was no rain until July 9. In the other years, from 1928 to 1934, there was no hot, dry period between June 15 and July 15, except in 1931. In this year, there was a very hot period just at the time of pupation, but it was accompanied by frequent rains.

Corn Refuse Clean-up and Population Variations

The enforced corn refuse clean-up administered by the Ontario Department of Agriculture was also a factor in reducing initial moth population in the years 1927, 1928 and subsequent years. The clean-up was first carried out in 1926 and the crop of 1927 was the first to benefit from it.

The importance of initial population and pupal mortality as a factor influencing this population has been brought to greater prominence in the present paper. This also further emphasizes the great importance of the corn refuse clean-up as a method of reducing initial population. The clean-up is of added importance as through it the corn stalks are worked in such a manner that at the completion of operations, the refuse left is lying prone on the soil surface, and if a hot, dry period does occur, the pupae are more certain to be killed than if the stalks were standing.

SUMMARY

A detailed quantitative study of the flight, oviposition and larval establishment periods in the life cycle of the European corn borer, *Pyrausta nubilalis* Hbn., and the physical factors affecting them has been made at Chatham, Ontario, Canada, during the years 1927 to 1936.

The methods of study have been outlined in some detail because of the quantitative methodical field treatment involved, and because some of the features of the study are a new approach to a field problem.

The seasonal limits of the flight period have been found to be on the average from July 1 to July 27, with the peak of flight usually taking place about July 9. The length of the flight season has averaged 26 days, but moths are usually absent for about 6 days during each season which would give an actual flight season of about 20 days. Moths were caught in the light trap earlier and later in the season than they were in the corn field, but the peaks of flight to corn and to light trap occur about the same period. Very late seasonal captures in the light trap have indicated the presence of a very small second generation of the borer in some years.

The largest flight occurred during the season of 1927 and the smallest during 1935, when only 29 moths were observed in the plot. Flight to light trap is of greater magnitude than that to the corn field during some years, while in others it is smaller.

In corn fields, the average percentage of males in flight has been 15.5. It has varied from 41% in 1934 to none in the years 1927 and 1928. The light trap catches, on the other hand, have averaged 74.7% males.

The protrandric tendency of males to emerge from the pupae before the time of emergence of the females is not carried over into the period of flight in the corn field. Males do not appear in the field before the females.

There is a period of a few days between emergence in the region and the flight of the moths to corn fields. The length of the period is longer than that of the preoviposition period. In some measure, the non-appearance of moths in the corn field for a considerable time after emergence might be explained by the fact that the males emerge from the pupae in greater numbers earlier than do the females.

Flight takes place each favourable night beginning about ½ hour before sunset. Moths continue in flight in numbers until about 3½ hours after sunset. Only about 2.7% of the moths fly after 4:30 Sunset time; 94.7%

of the moths fly between ½ and 4½ hours after sunset, while 79.4% fly in the shorter period between ½ hour and 2½ hours after sunset. The period of flight is quite definite year after year. No sexual differences in the time of night of flight were noted.

The general subject of the time of activity of nocturnal insects has been discussed. The corn borer moth flies at the same period of the night as do certain other Lepidoptera, but the literature upon the subject is not extensive. Most of the studies, upon·the time of night of the activity of nocturnal insects, are based upon captures in light traps. In the present study, measurements of flight activity have been secured of the actual flight, over plots of the host plant of the insect and are therefore, possibly of more value in that they are truer to actual conditions. The biological question as to why insects fly at night and usually at definite periods, although constantly in mind, has not been answered in the case of the corn borer. Some light on the subject was sought in the correlation of temperature, humidity, atmospheric pressure and time of sunset, with the appearance of the first moth each night, but no correlation with any of these factors was found.

The value of light traps in the study of the biology and periodicity in insects has been discussed. It is shown that no relationship exists between the magnitude of flight in the corn field and that indicated by light trap catches. The seasonal abundance of the borer cannot be judged by the attraction of adults to light traps. This conclusion supports that of Cook, who found that the capture of noctuid moths in a light trap is not a reliable index upon which to judge the numbers present within a given season. The present work demonstrated that the light trap is a better measure to determine the seasonal limits of flight than is any individual corn field.

The value of using Sunset time in the study of flight activities of nocturnal insects has been pointed out. Sunset time allows a direct comparison to be made of the times of activity of insects and with more accuracy than if civil time was used.

The optimum temperature for flight was found to be between 65° F. and 70° F. The lowest temperature at which flight was observed was 56° F., but generally flight is terminated at 58° F., or 59° F. Low temperatures prohibit flight much more quickly than do high temperatures. A lowering of the temperature from 65° F. reacts more quickly on flight activities than does a rise from 75° F.

There is a positive relationship between temperature and flight activities. Temperature on individual nights regulates moth flight. A rise in temperature causes an increase in the numbers of moths in flight and a decrease in temperature causes a decrease in number or if low enough, a cessation.

The optimum temperatures and other relationships in the corn borer are very close to those found by other authors for codling moth and bud moth.

Average seasonal temperatures apparently have no regulative action on the duration of the flight season as has been suggested in the literature. The flight season was longest in the 2 years with the lowest average tem-

peratures, but in all other cases, seasonal temperature did not affect the length of flight season. The shortest period did not occur in the hottest and driest season.

It is demonstrated that during the 10-year period, most moths flew at high humidities. Ninety per cent of the moths flew at humidities indicated by saturation deficiencies of 0 mm. to 6 mm. No correlation, however, could be found between moth flight and humidity on individual nights. The influence of temperature is so great that any effect of humidity is masked.

Wind, at velocities at least up to 17 miles per hour, has no effect upon flight. This was the highest velocity experienced during the 10-years' observations. Rain, on the other hand, will prohibit flight if heavy enough. Rain at the rate of 0.14 inches an hour usually prohibits flight. Moths will fly in light rains.

The effect of the electrical state of the atmosphere during and immediately after thunder storms was observed, but the results are conflicting. In one case, adults flew immediately after the storm and in another case they did not fly for at least 2 hours.

It has been shown that lunar periodicity does not influence the time of occurrence of the annual flight cycle or that of daily rhythm.

Atmospheric pressure, within nightly periods or for longer intervals, does not influence flight. The same is true also of mists or fogs, and cloudiness.

Moisture in the form of dew and guttation has been considered from the viewpoint of the necessity of water for the normal life of the adult, but no relationship with insect activity could be found. Water of guttation usually appears before dew, and in some cases dew does not appear and water from guttation is the only moisture present.

The egg laying season, naturally, follows that of flight, but there is a difference in the rate of development of peaks in different years. In some seasons, conditions are earlier more favourable to egg laying than they are to flight and *vice versa*.

The number of eggs laid per female per 100 plants per season has averaged 8.5. The poorest years for egg laying were 1927 and 1928, and the best years were 1934, 1935 and 1936. The first 2 years were the coolest and wettest experienced, while the second group were the hottest and, on the whole, the driest years. Temperatures on individual nights did not influence the number of eggs laid per female per night. Ninety-four per cent of the eggs are laid on the lower surface of the leaves 5% on the upper surface and 0.5% on the culm.

Egg mortality has averaged 16.8%, thus giving an average survival of 83.2%. Mortality from dislodgement of egg masses from the plants has averaged 11.3%, while in one year, 1934, it amounted to 34%. Increased mortality above the average through dislodgement is due to a series of alternate hot days and cold nights. In 1934, the series of days causing dislodgement consisted of those having a maximum temperature of 90° F., with a minimum temperature of 52° F. The humidity at the time was fairly high, the average saturation deficiency being 6.2 mm. It is suggested that during such a period of weather the egg masses are mechanically

loosened from the leaves by the alternate wilted and turgid condition of the leaves during the daily cycle. This type of weather is also conducive to heavy guttation and this might also help loosen the egg masses. Formerly, it was thought that egg masses were dislodged by the action of heat and desiccation during hot, dry periods. Egg masses were not dislodged at Chatham during continued hot, dry periods.

The mortality of eggs remaining upon the leaves is consistently low, averaging 5.8%. Because of the uniformly low mortality, it was impossible to learn anything about the factors causing this mortality in the field. It was not due to parasites or predators.

Egg masses laid on the upper surface had about the same mortality rate as those laid on the under surface of the leaf. Other authors have reported a high mortality in eggs placed on the upper surface of the leaves.

Larval mortality in establishment was found to average 72.1%, or a survival of 27.9%. It varied from a survival of 57.2% in 1931 to as low as 7.6% in 1930. Increased larval mortality is caused by sudden heat waves and is independent of humidity. In 1930, the mean daily temperature rose from an average daily temperature of 58° F., to an average of 73° F. within 2 days and to an average of 80° F. within 3 days. This sudden rise from a low average daily temperature to a high one increased larval mortality to 92.4%. It has been shown that rain and hot, dry periods do not greatly affect larval mortality. The importance of these two factors has been over-emphasized in the literature. Sudden heat waves have not before been suggested as causing increased larval mortality.

Borer activity and climatic factors have been studied by correlating them within 5-day periods. A climatograph for the microclimate of the plots within each 5-day period has been devised, plotting for the first time the average temperature with the average saturation deficiency.

The number of female moths in flight annually, the number of eggs laid per female per 100 plants per season and the total percentage survival have been studied and measured and related by the use of the population index to field populations over wide areas.

The population index is expressed by the formula $PI = (AB)C$, where A is the number of females in flight, B the number of eggs laid per female per 100 plants per season and C the total seasonal survival.

It has been shown that the magnitude of the population index shows the trend of borer population in wide areas, thus indicating that the physical factors causing variations in observational plots are also acting over wide areas. Temperature and humidity are generally similar in wide areas, while rain and wind are more local in character. It has previously been shown that wind and rain have little effect on larval survival, while temperatures of certain characteristics greatly increase larval mortality.

The biotic factors contributing most largely to annual fluctuations in borer populations during the period in the life cycle of the borer under study have been shown to be initial available moth populations, larval survival, egg production per female and egg mortality.

The years under study have been classified according to their favourableness to corn borer development. The year 1928 was favourable,

The years 1932, 1933 and 1936 were above average in favourableness, the years 1929, 1931 and 1935 below average in favourableness, and 1930 and 1934 were very unfavourable.

The biotic factors causing a decrease or increase in borer population in each year are as follows: during 1929, a decrease took place because of a low initial moth population and poor larval survival; in 1930, a decrease occurred because of extremely low larval survival; in 1931, an increase occurred because of very favourable larval survival; in 1932, an increase in borer population occurred because of favourable moth population and increased egg production per female; in 1933, an increase occurred because of favourable moth population; in 1934, a decrease occurred because of low moth population and low egg survival; in 1935, an increase occurred because of greater egg production per female and increased larval survival; and in 1936, an increase occurred because of a high moth population.

It has been shown that pupal mortality and corn refuse clean-up are two important factors influencing the available moth population. The climatic conditions causing pupal mortality in 1934 are given in some detail. Similar conditions were present only in the years 1927 and 1928 when large reductions in borer populations took place. These reductions are, no doubt, due partly to the clean-up of corn refuse and partly to pupal mortality.

The factors causing population fluctuations are complex, and in many cases, interdependent. The important factors, however, causing fluctuations in borer population have been found to be initial moth population, larval survival, egg production, egg mortality, pupal mortality and corn refuse clean-up. Temperature, especially temperature of certain definite characteristics, has been shown to have a great influence upon most of these factors, but especially upon the rate of larval establishment, pupal mortality, egg mortality, and the number of eggs produced.

ACKNOWLEDGMENTS

This work has been a part of the research activities on the European corn borer, carried out at the Dominion Entomological Laboratory, Chatham, Ontario, Canada. Grateful acknowledgment is due to the Entomological Branch, Dominion Department of Agriculture, and to Dr. Arthur Gibson, Dominion Entomologist, for permission to use the data presented.

Thanks are also due to Mr. H. G. Crawford, Chief of the Division of Field Crop and Garden Insects, Entomological Branch, to which the Chatham Laboratory is attached, for his interest in the work, his many helpful suggestions and for his administrative support.

The quantitative nature of the work is the result of suggestions made by Dr. R. N. Chapman, former Chief of the Division of Entomology and Economic Zoology, University of Minnesota.

The field work in connection with the study could not have been carried out without the assistance of my colleagues at the Chatham Laboratory. Those formerly stationed at the Laboratory and associated with the work have been the following: Messrs. R. M. Aiton, F. F. Smith, W. E. Lindsay, and Doctors J. A. Adams, W. E. van Steenburgh and

W. E. Heming. Of the present laboratory staff, Dr. Geoffrey Beall and Mr. D. A. Arnott have been closely associated with the work. Dr. Beall spent approximately five seasons from 1932-36, inclusive, doing the flight and oviposition studies in the field. He also contributed yearly reports and analysis of work. During this time, he contributed many important improvements in procedure and methods of analysis. Mr. Arnott assisted in flight studies during one season and oviposition studies during three seasons.

The excellent workmanship in typewriting, in the arrangement of tables and final attractive form of the typescript was largely the result of the work and co-operation of Miss Margaret Ronson, of the laboratory staff.

Acknowledgments are due to my wife, Ethel Lenore Morrison Stirrett, for her kindly interest and support during the progress of the work and for her active help in checking manuscript and other data.

The progress of the work has been greatly influenced by frequent discussions and conferences with various officials interested in research upon the European corn borer. Especial mention should be made of the advice and criticisms given by Professor L. Caesar, Provincial Entomologist of Ontario and Professor of Economic Entomology at the Ontario Agricultural College, Guelph, Ontario; Mr. D. J. Caffrey, Senior Entomologist, United States Bureau of Entomology and Plant Quarantine, formerly in charge of Corn Borer Research and Dr. L. L. Huber of the Ohio Agricultural Experiment Station, Wooster, Ohio.

Acknowledgment is hereby made to Mr. G. A. Ficht, Purdue Agricultural Experiment Station, for supplying detailed weather records taken by him at Auburn, in northern Indiana.

Doctors A. C. Hodgson and F. R. Immer of the University of Minnesota have been consulted in regard to certain phases of the work and have given advice and suggestions.

Dr. A. A. Granovsky, of the Division of Entomology and Economic Zoology, University of Minnesota, has acted as faculty advisor. His interest in the problem, his helpful suggestions and criticisms have been invaluable and greatly appreciated.

(Concluded)

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WORLD ECONOMISTS TO MEET IN CANADA

The fifth meeting of the International Conference of Agricultural Economists will be held at Macdonald College, Ste. Anne de Bellevue, Quebec, August 21–28, 1938. This Conference will be attended by Agricultural Economists from more than 25 countries.

The Conference was first organized in 1929. It came about as a result of discussions between Dr. C. S. Orwin, Director of the Agricultural Economics Research Institute, Oxford, England, Dr. C. E. Ladd, Department of Agricultural Economics, Cornell University, Ithaca, N.Y., the late Dr. G. F. Warren, Department of Agricultural Economics, Cornell University, Ithaca, N.Y., and Mr. L. K. Elmhirst, Dartington Hall, Totnes, Devon, England. The first meeting was held at Mr. Elmhirst's Estate; the second at Cornell University, Ithaca, N.Y.; the third at Bad Eilsen, Germany; and the fourth at St. Andrews University, St. Andrews, Scotland.

The purpose of the Conference is to bring together periodically Agricultural Economists from all parts of the world to discuss international economic problems affecting agriculture and to discuss common problems in carrying on research.

The officers at present are: President, L. K. Elmhirst; Vice-President, Dr. Max Sering, University of Berlin, Berlin, Germany; Honorary-Secretary, J. R. Currie, Research Department, Dartington Hall, Totnes, Devon, England. The late Dr. G. F. Warren was also a Vice-President. Each country may elect a member to the Council for every ten members but no country shall have more than three members. The Canadian representatives are Dr. J. F. Booth, Economics Division, Marketing Service, Dominion Department of Agriculture, Ottawa; Dr. W. Allen, Canadian Agricultural Commissioner, London, England, and Dr. J. E. Lattimer, Department of Farm Economics, Macdonald College, P.Q The arrangements of the Conference are in the hands of a committee of which Dr. Lattimer is Chairman and Joseph Coke, Economics Division, Marketing Service, Dominion Department of Agriculture, Ottawa, is Secretary.

Among those who will be in attendance are Secretary Wallace, United States Department of Agriculture, Washington, D.C.; Dr. C. Meyer, Berlin, Germany; Dr. V. Brdlik, Institute of Agricultural Accountancy and Economics, Praha, Czechoslovakia; Dr. S. L. Descartes, College of Agriculture and Mechanic Arts, University of Puerto Rico, Rio Piedras, P.R., West Indies; Mr. A. H. Cockayne, Director of Agriculture, Wellington, New Zealand; Prof. C. Lorenzoni, Florence, Italy; Prof. C. Ihrig, Budapest, Hungary; Dean C. E. Ladd, Department of Agricultural Economics, Cornell University, Ithaca, N.Y.; Prof. Asher Hobson, Department of Agricultural Economics, University of Wisconsin, Madison, Wis.; Prof. A. W. Ashby, Department of Agricultural Economics, University College of Wales, Aberystwyth; W. H. Senior, Department of Agriculture for Scotland, Edinburgh; A. W. Menzies Kitchen, School of Agriculture, Cambridge, England; Miss Ruth Cohen, Agricultural Economics Research Institute, Oxford; G. S. Bennett, Imperial Economic Committee, London, England; Prof. S. Schmidt, Krakow University, Krakow, Poland; Prof. P. Starcs, Jelgava, Latvia; Ramon Fernandez y. Fernandez, National University of Mexico, Mexico City; D. A. E. Harkness, Ministry of Agriculture, Government of Northern Ireland, Belfast; and Prof. H. C. M. Case, University of Illinois, Urbana.

The program will centre about four main themes:—Social Implications of Economic Progress in Present Day Agriculture, Land Tenure and the Social Control of Land Use, Farm Labour and Socia Standards, and International Trading in Relation to Agricultural Development.

Round table discussions will be arranged on the use of International Statistics of Agriculture, Farm Management Research, Marketing Research, Price Analyses, Rural Rehabilitation and Resettlement. In addition, there will be a series of papers dealing with a wide variety of subjects.

SCIENTIFIC AGRICULTURE

Vol. XVIII AUGUST, 1938 No. 12

SOIL STUDIES OF BROWN ROOT ROT OF TOBACCO

I. Effect of Certain Crop Residues on Some Forms of Nitrogen[1]

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(Received for publication April 2, 1938)

INTRODUCTION

Brown root rot of tobacco is a disease that is widely prevalent in the tobacco-growing districts of eastern Canada and the United States. A number of papers have been published within the last ten or fifteen years dealing with various aspects of the trouble, but as yet the fundamental cause of the disease is unknown.

Johnson (6) in 1924, pointed out that brown root rot is distinct from black root rot of tobacco, the latter being due to the fungus *Thielavia basicola*. Brown root rot can be controlled by sterilization of soils with either heat or formaldehyde, but the casual agent persists in the soil from year to year, though it may die out under excessive drying or absence of the host plant. The cause may have some connection with other crops as the disease is common on sod land the first year planted with tobacco. Relatively cool weather seems to favour the disease. Drying or aeration of the soil is favourable to recovery.

In Kentucky (10), the disease was found to be quite severe following a crop of corn, chiefly on fields of low available fertility. Though several organisms were isolated from rotten roots, it could not be shown that any particular one was the cause of the trouble. Dead corn roots from a continuous corn plot, introduced into sand cultures, caused a similar disease in tobacco.

In 1926, it was reported from Connecticut (1) that no specific organism was found associated with brown root rot of tobacco. Sterilization with steam and formaldehyde prevented the disease, thus suggesting it was caused by an organism. On the other hand, aerating the soil in a thin layer for two weeks also prevented the disease, and no known pathogen can be destroyed by such mild treatment. The disease seemed to be associated with preceding crops and cover crops, *e.g.* timothy, though many fields cropped alike for several years showed the disease only in patches. The soil reaction had no influence and the application of additional fertilizers did not help.

Johnson, Slagg and Murwin (7) found evidence which led them to believe that the cause of this disease might be either parasitic or non-

[1] Contribution from the Division of Chemistry, Central Experimental Farm, Ottawa, Ont.
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parasitic. The physical condition and acid-reaction of the soil were not responsible. Soil temperature was important but soil moisture was not very important, though dry weather favoured the disease. A large part of the injurious agent seemed to exist in the organic matter.

Doran (4) working with timothy infusions, was able to induce a disease similar to the brown root rot. He found the toxicity of the infusions varied with age and thought that perhaps toxins were formed in the decomposition of the organic material.

Thomas (9) believed that the trouble was due to lack of nitrates in the early spring, cellulose decomposers using up all available nitrogen and leaving none for the tobacco plants which need an abundance in the early stages of growth. No brown root rot resulted when applications of 3,000 lbs. $(NH_4)_2$ SO_4 and 6,000 lbs. superphosphate per acre were made.

Eisenmenger (5) worked on the theory that aluminum poisoning was responsible. He found no evidence either that crops such as corn and timothy released aluminum, or that toxicity with excess aluminum produced the symptoms of the brown root rot disease.

Beaumont (3) put forward a hypothesis to explain the disease, based on his observations over a period of years. He suggested that the unoxidized forms of nitrogen, resulting from the decomposition of plant residues, are responsible for the occurrence of brown root rot, not because these forms of nitrogen are directly toxic to the plant, but because they set up conditions in the roots which permit them to be readily attacked by common decay organisms.

EXPERIMENTAL METHODS

In starting an investigation into the causes of brown root rot of tobacco in this laboratory, it was decided to study the occurrence of some of the forms of nitrogen in the soil, and how the amounts of these were affected by additions of the residues, *i.e.* roots and stubble, of certain crops. Three series of experiments were run. In the first, a light sandy soil from the experimental plots of the Division of Chemistry, Central Experimental Farm, Ottawa, was used. The samples collected were air-dried and screened through a 2 mm. screen. Samples of the stubble of timothy, corn, alfalfa and oats were also collected, air-dried and coarsely ground in a Wiley mill.

Samples of about 1½ kg. of soil were remoistened to about 60% of their water holding capacity, treated as shown below, kept in the laboratory in large, loosely-stoppered glass bottles, and portions withdrawn at intervals for analysis.

The treatments used were as follows:—

1. Soil from corn plot—nothing added.
2. Soil from corn plot—about 1.5% ground corn stubble.
3. Soil from corn plot—$MgCO_3$ at the rate of approximately 1,000 lb. per acre.
4. Soil from corn plot—both $MgCO_3$ and corn stubble, as above.
5. Soil from corn plot—$CaCO_3$ at the rate of approximately 2 tons per acre.

6. Soil from corn plot—both $CaCO_3$ and corn stubble as above.
7. Soil from timothy plot—nothing added.
8. Soil from timothy plot—about 1.5% ground timothy stubble.
9. Soil from timothy plot—$MgCO_3$ at the rate of approximately 1,000 lb. per acre.
10. Soil from timothy plot—both $MgCO_3$ and timothy stubble as above.
11. Soil from timothy plot—about 1.5% ground corn stubble.
12. Soil from alfalfa plot—nothing added.
13. Soil from alfalfa plot—about 1.5% ground alfalfa stubble.

Methods of Analysis

Results are presented showing the amount of ammonia, nitrite, and nitrate-nitrogen in these samples at intervals of several weeks after treatment. In determining the ammonia, the soil was extracted with 10% NaCl solution, filtered, and the filtrate distilled from excess MgO, the ammonia being collected in standard 0.02N H_2SO_4. This is essentially the method of McLean and Robinson (8).

For the determination of nitrites and nitrates, the extracting solution used was distilled water containing 1.2 g. aluminium sulphate as recommended by Bartholemew (2) for nitrites. Calcium hydroxide was used to clarify the solution after shaking. Nitrites were determined colorimetrically, using sulphanilic acid and alphanaphthylamine to develop the colour. Nitrates were determined by the phenoldisulphonic acid method.

RESULTS

First Series

Tables 1, 2, and 3 show the results obtained for ammonia, nitrites and nitrates respectively with the first series. It will be seen that in the great majority of cases, the ammonia content is below 5 p.p.m. The only cases where there is any considerable accumulation of ammonia is in Sample 13, soil treated with alfalfa stubble, after 2, 6 and 10 weeks. In

TABLE 1.—AMMONIACAL NITROGEN IN SOILS FROM CHEMISTRY DIVISION PLOTS
(Expressed in p.p.m. oven dry soil)

Treatment No.	Time of Analysis (weeks after treatment)				
	2 weeks	6 weeks	10 weeks	15 weeks	21 weeks
1	12.6	—	3.4	2.2	1.8
2	8.7	2.7	3.7	1.0	2.8
3	6.9	0	1.7	0.5	1.9
4	2.4	1.2	1.7	0.5	0.9
5	3.5	0	2.5	0.5	1.4
6	3.5	2.0	3.0	0.5	1.4
7	4.6	4.5	3.2	0.5	3.1
8	3.7	2.9	3.2	0	2.6
9	4.6	3.3	1.8	0.5	2.1
10	0.8	3.7	6.8	0	2.0
11	3.7	7.7	6.2	0.5	1.5
12	0.8	3.5	2.5	0	2.4
13	88.8	58.9	62.6	6.3	4.8

TABLE 2.—NITRITE-NITROGEN IN SOILS FROM CHEMISTRY DIVISION PLOTS
(Expressed in p.p.m. oven-dry soil)

Treatment No.	Time of Analysis (weeks after treatment)				
	2 weeks	6 weeks	10 weeks	15 weeks	21 weeks
1	0.7	0.3	0.5	0.2	0.2
2	0.3	0.3	0.5	0.2	0.3
3	0.3	0.2	0.4	0.3	0.4
4	0.4	0.3	0.4	0.2	0.3
5	0.4	0.3	0.3	0.2	0.1
6	0.4	0.4	0.4	0.3	0.2
7	0.5	0.3	0.6	0.3	0.2
8	0.5	0.3	0 6	0.3	0.2
9	0.5	0.4	0.6	0.2	0.2
10	0.4	0.4	0.6	0.4	0.2
11	0.5	0.3	0.7	0.2	0.2
12	0.3	0.3	0.6	0.3	0.2
13	6.8	5.2	18.7	0.5	0.3

TABLE 3.—NITRATE-NITROGEN IN SOILS FROM CHEMISTRY DIVISION PLOTS
(Expressed in p.p.m. oven-dry soil)

Treatment No.	Time of Analysis (weeks after treatment)				
	2 weeks	6 weeks	10 weeks	15 weeks	21 weeks
1	49	81	113	141	132
2	4	57	137	146	143
3	67	81	197	154	190
4	2	74	137	124	196
5	147	87	166	241	194
6	14	53	154	267	206
7	203	186	296	222	307
8	8	126	182	208	253
9	177	180	364	320	264
10	8	113	216	215	256
11	47	174	556	254	270
12	114	128	145	197	211
13	168	246	663	791	532

Table 3, however, it is shown that in these cases there are also large accumulations of nitrate-nitrogen, so that there is no evidence of nitrification being inhibited.

Table 2 shows that the content of nitrite-nitrogen is extremely low in practically all cases. As with ammonia, the exceptions are in Sample 13, after 2, 6, and 10 weeks, but as pointed out above there are also large accumulations of nitrate-nitrogen in these cases.

In examining the figures for nitrate-nitrogen as given in Table 3, it will be seen that the addition of stubble (with the exception of alfalfa stubble—Sample 13) causes a considerable reduction in the amount of nitrates present at the time of the first analysis. According to Waksman (11), this is to be expected when organic materials of a wide C : N ratio are introduced into soil. As the decomposition of the material proceeds and the C : N ratio becomes sufficiently narrow, there will be a normal

accumulation of nitrate-nitrogen in the soil. The fact that the addition of alfalfa stubble (Sample 13) did not cause a lowering of the nitrate content after two weeks, is probably due to the higher nitrogen content of this material. The amounts of nitrogen in the samples of stubble used were found to be as follows:—

Corn stubble	0.62% N
Timothy stubble	0.74% N
Alfalfa stubble	2.29% N
Oat stubble	0.59% N

The addition of $CaCO_3$ seems to have increased the accumulation of nitrate-nitrogen somewhat, if averages of the five analyses of each sample are compared. (Compare No. 1 with No. 5, and No. 2 with No. 6.) The effect of adding $MgCO_3$ was less than that of $CaCO_3$. No other effects of these treatments are apparent.

Second Series

The second series of experiments was run on soil samples from the Dominion Experimental Station at Harrow, Ont. The samples available were as follows:—

Sample 2. Soil on which timothy was grown in 1936.

Sample 3. Soil on which corn was grown in 1935 and where severe brown root rot was shown in 1936.

Sample 4. Soil on which corn was grown in 1936.

Sample 5—Soil on which no corn, timothy or tobacco had been grown since 1930.

All four were remoistened to about 60% of their water-holding capacity and kept in bottles as described for the first series. In addition, portions of Samples 2 and 5 were treated with various crop residues, as follows:—

Sample 2C—about 1.5% of corn stubble
Sample 2O—about 1.5% of oat stubble
Sample 2T—about 1.5% of timothy stubble
Sample 2A—about 1.5% of alfalfa stubble
Sample 5C—about 1.5% of corn stubble
Sample 5O—about 1.5% of oat stubble
Sample 5T—about 1.5% of timothy stubble.

Nitrites and nitrates, but not ammonia, were determined at weekly intervals for a period of several weeks, and the results obtained are presented in Tables 4 and 5. Results for the 4 untreated soils are grouped together, so that they can be more easily compared.

From Table 4 it can be seen that as in the first series, there was at no time any accumulation of nitrite-nitrogen, not even with the sample (2A) which received alfalfa stubble.

The results given in Table 5 would indicate that, of the 4 untreated soils, Sample 5 shows the highest and most rapid accumulation nitrates.

TABLE 4.—NITRITE-NITROGEN IN HARROW SOILS, INCUBATED AT ROOM TEMPERATURE (Expressed in p.p.m. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)									
	1	2	3	4	5	6	7	8	9	10
Untreated soils										
No. 2	0.4	0.6	0.5	0.5	0.5	0.5	0.3	0.5	0.4	0.3
No. 3	0.3	0.3	1.0	0.4	0.7	0.3	0.2	0.3	0.2	0.3
No. 4	0.4	0.3	0.9	0.4	0.7	0.4	0.3	0.3	0.2	0.2
No. 5	0.5	0.4	0.7	0.8	0.7	0.4	0.2	0.4	0.3	0.3
Treated soils										
No. 2—untreated	0.4	0.6	0.5	0.5	0.5	0.5	0.3	0.5	0.4	0.3
No. 2+ corn stubble	0.4	0.5	0.9	0.3	0.8	0.7	0.5	0.3	0.4	0.4
No. 2+oat stubble	0.3	0.5	0.5	0.3	0.4	0.5	0.3	0.5	0.4	0.3
No. 2+timothy stubble	0.4	0.5	0.9	0.4	0.4	0.6	0.5	0.3	0.2	0.3
No. 2+ alfalfa stubble	0.4	0.4	0.8	0.6	0.8	0.7				
No. 5—untreated	0.5	0.4	0.7	0.8	0.7	0.4	0.2	0.4	0.3	0.3
No. 5+ corn stubble	0.4	0.3	0.6	0.7	0.4	0.3	0.3	0.5	0.3	0.3
No. 5+oat stubble	0.5	0.3	0.7	0.7	0.5	0.3	0.3	0.5	0.3	0.2
No. 5+timothy stubble	0.4	0.4	0.8	1.0	0.6	0.4	0.2	0.3	0.3	0.2

TABLE 5.—NITRATE-NITROGEN IN HARROW SOILS, INCUBATED AT ROOM TEMPERATURE (Expressed in p.p.m. oven dry soil)

Sample	Time of Analysis (weeks after treatment)									
	1	2	3	4	5	6	7	8	9	10
Untreated soils										
No. 2	35	50	63	83	66	100	153	141	178	133
No. 3	10	27	58	71	68	117	111	124	144	127
No. 4	30	32	36	40	90	61	84	88	184	196
No. 5	55	64	176	195	229	171	295	277	265	316
Treated soils										
No. 2—untreated	35	50	63	83	66	100	153	141	178	133
No. 2+ corn stubble	7	8	5	36	58	80	71	157	160	141
No. 2+oat stubble	6	5	5	3	4	Tr.	Tr.	Tr.	5	Tr.
No. 2+timothy stubble	4	4	12	8	15	18	39	82	96	95
No. 2+alfalfa stubble	9	107	451	728	760	656				
No. 5—untreated	55	64	176	195	229	171	295	277	265	316
No. 5+corn stubble	—	58	139	156	143	197	203	173	165	280
No. 5+oat stubble	—	Tr.	6	Tr.	Tr.	Tr.	4	5	13	29
No. 5+timothy stubble	25	30	54	108	112	114	180	171	188	213

It might be mentioned that this soil was obtained from a poultry paddock. It does not, however, show the highest percentage of total nitrogen as will be seen from the following figures:—

Sample 2.—0.080% total N.
Sample 3.—0.085% total N.
Sample 4.—0.064% total N.
Sample 5.—0.072% total N.

As in the first series, so also here, the addition of crop residues to the soil samples causes an initial depression in the amount of nitrates present. Even alfalfa has caused a low content of nitrates after one week, but in

two weeks the amount present is much above that in the untreated soil, which agrees with the results from the first series. Of the other three crop residues used, oats caused the most prolonged depression in amount of nitrates, with only a trace being present even after ten weeks with Sample 2. With Sample 5 however, a small accumulation is found after nine and ten weeks. In both soil samples, also, the effect of timothy residues in keeping down the accumulation of nitrates, is probably slightly more than the effect of the corn residues.

Third Series

The third series of experiments was run on Samples 3 and 4 from Harrow. These were treated with crop residues as were Samples 2 and 5 in the second series, but they were placed in the ice-box and allowed to incubate at a temperature of approximately 10° C. This procedure was suggested by the reported observation that brown root rot is favoured by low soil temperatures. In addition to determining the amount of ammonia, nitrite-, and nitrate-nitrogen at intervals, it was decided to determine exchangeable hydrogen and exchangeable calcium as well.

To obtain the exchangeable bases, 50 grams of soil were treated with about 100 cc. of neutral normal ammonium acetate solution, filtered and washed with more of the solution until the filtrate measured 200 cc. A 50 cc. aliquot was then titrated potentiometrically, using N/5 NH_4OH, until a reading corresponding to the pH of the neutral ammonium acetate solution was reached, the exchangeable hydrogen being calculated from the amount of standard ammonium hydroxide used. The remaining 150 cc. of solution was taken to dryness after being acidified with a few drops of conc. HCl, ignited at 450°–500° C. to destroy organic matter, and calcium was determined in the residue by standard procedure.

The results obtained in this series are presented in Tables 6, 7, 8, 9, and 10. The amount of ammonia present exceeds 10 p.p.m. in only 3 cases at the time of the first analysis, and in most of the other cases it is quite low. There is no appreciable amount of nitrite-nitrogen at any time.

In Table 8, the effect of adding stubble on the accumulation of nitrates in the soil samples is again shown. The effect of the oat stubble persists

TABLE 6.—AMMONIA NITROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in p.p.m. oven dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
No. 3—untreated	11.9	7.6	2.9	1.0	7.8	5.1
No. 3+corn stubble	6.6	—	0.5	0.9	6.9	8.1
No. 3+oat stubble	12.0	1.4	1.4	2.8	8.1	5.5
No. 3+timothy stubble	2.9	1.9	2.9	0.9	—	—
No. 4—untreated	5.8	2.9	3.4	3.8	7.5	8.2
No. 4+corn stubble	0.5	2.9	1.4	1.0	6.3	6.6
No. 4+oat stubble	14.4	1.0	1.4	0.5	5.8	2.3
No. 4+timothy stubble	0	0.5	1.4	1.4	7.2	5.1

TABLE 7.—NITRITE-NITROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in p.p.m. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3—untreated	0.2	0.2	0.2	0.2	—	0.3
3+corn stubble	0.3	0.3	0.3	0.3	—	0.3
3+oat stubble	0.3	0.2	0.3	0.2	—	0.5
3+timothy stubble	0.2	0.2	0.3	0.3	—	—
4—untreated	0.3	0.2	0.3	0.4	—	0.5
4+corn stubble	0.2	0.2	0.3	0.3	—	0.2
4+oat stubble	0.2	0.2	0.3	0.3	—	0.3
4+timothy stubble	0.2	0.2	0.3	0.4	—	0.2

TABLE 8.—NITRATE-NITROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in p.p.m. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3—untreated	15	78	98	181	103	99
3+corn stubble	4	Tr.	6	39	77	129
3+oat stubble	8	Tr.	4	5	4	7
3+timothy stubble	5	Tr.	4	11	23	—
4—untreated	15	31	36	32	54	55
4+corn stubble	10	Tr.	4	3	13	37
4+oat stubble	12	Tr.	4	3	Tr.	7
4+timothy stubble	4	Tr.	4	3	Tr.	14

TABLE 9.—EXCHANGEABLE HYDROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in milliequivalents per 100 g. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3 untreated	3.0	2.6	2.9	2.6	2.7	3.6
3+corn stubble	2.8	2.5	2.7	2.2	2.4	3.6
3+oat stubble	3.3	2.8	2.6	2.4	2.2	2.9
3+timothy stubble	3.0	2.1	2.9	2.2	2.4	—
4—untreated	3.3	2.7	3.1	2.6	2.4	3.1
4+corn subble	4.0	2.8	2.9	2.7	2.5	3.3
4+oat stubble	3.3	3.0	3.1	2.4	2.4	3.6
4+timothy stubble	3.7	2.7	2.6	2.4	2.4	3.1

TABLE 10.—EXCHANGEABLE CALCIUM IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in milliequivalents per 100 g. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3–untreated	2.6	2.8	2.7	2.7	2.7	2.8
3+corn stubble	2.7	2.9	2.9	2.7	2.8	2.9
3+oat stubble	2.8	3.5	3.6	3.4	3.1	3.3
3+timothy stubble	2.8	3.1	3.0	3.0	2.8	—
4—untreated	2.7	2.9	2.8	2.8	2.7	2.9
4+corn stubble	2.8	2.9	2.9	2.8	2.8	3.0
4+oat stubble	2.9	3.1	3.0	3.0	3.0	3.2
4+timothy stubble	2.9	3.1	3.1	3.0	2.9	3.2

longest, and the effect of the corn stubble seems to disappear before that of the timothy stubble. This agrees with the results of the second series.

The variations in the amounts of exchangeable calcium and exchangeable hydrogen are small. There seems to be no effect on these two constituents from the addition of stubble, which, in the case of the hydrogen, may be interpreted to mean that there is no appreciable change in the acidity of the soil due to these treatments.

SUMMARY

Soil samples from the Chemistry Division plots at the Central Experimental Farm, Ottawa, and from the Dominion Experimental Farm at Harrow, Ont., were treated with the ground-up residues (stubble and roots) of corn, timothy, oats and alfalfa, and maintained at a moisture content corresponding to about 60% of the water-holding capacity of the soils. Two series were kept at room temperature (about 20°–25° C.) and a third at about 10° C. Analyses were made at intervals for ammonia, nitrite-, and nitrate-nitrogen. The following conclusions are drawn from the results obtained:—

1. The addition of the residues of these plants does not cause any appreciable accumulation of ammonia in the soil. One exception is shown in one case with alfalfa stubble, but in that case there is also a large accumulation of nitrate-nitrogen.

2. The addition of the residues of these plants does not cause any appreciable accumulation of nitrites in the soil (with the one exception mentioned under 1).

3. All residues cause an initial depression in the accumulation of nitrates. The effect of alfalfa was quite brief, that of corn was less than that of timothy, and that of oats lasted longest.

4. Incubation of soil samples at 10° C. did not cause any accumulation of ammonia or nitrites, and nitrates accumulated as would be expected, perhaps somewhat more slowly due to the effect of the lower temperature on the activities of the microorganisms.

5. The addition of these plant residues seems to have no effect on the exchangeable hydrogen or exchangeable calcium.

6. It does not appear from these studies that corn or timothy residues (brown root rot of tobacco seems to follow both of these crops) have any more pronounced effect on the three forms of nitrogen studied than has oats residues, when the same amount of each is added to the soil. All depress the initial accumulation of nitrates, but the effect of corn and timothy disappear before that of oats.

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THE CHEMICAL COMPOSITION OF RUSSIAN THISTLE (*SALSOLA PESTIFER* A. NELS)[1]

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[Received for publication April 20, 1938]

Russian thistle (*Salsola pestifer* A. Nels) is an annual weed thought to have been introduced to the Dakotas from Russia about 1873. Although classified as a secondary noxious weed, it has in recent years become widespread throughout the desert plains and foothill areas of the United States and in the southern parts of Alberta, Saskatchewan and Manitoba. It is well adapted to dry conditions, and consequently, although it cannot compete successfully with a good stand of grain, will thrive where crops have failed owing to drought. By its rapid invasion of lands permanently or temporarily abandoned, it has retarded soil drifting and served as an emergency feed when nothing else has been available. Owing to its spiny leaves, high ash content, and its rigid, bulky structure, which makes it difficult to cure and store, it is not to be considered a particularly desirable feed. However, the severe drought in Saskatchewan during the season of 1937 forced many farmers to use it as livestock feed. As little information regarding its feeding value was available, it was thought necessary to study some of the problems connected with its use. A general discussion of the practical aspects of utilization of Russian thistle as livestock feed has already been published (2). It is the purpose of this paper to present the analyses made on a series of samples gathered at various stages of maturity and from various types of soil.

The samples were obtained from the environs of Saskatoon between July 31 and October 18, 1937 and were selected to represent different stages of growth from early bloom to complete ripeness, when the plants were ready to break off at the ground level.

The analyses are given in Table 1. For comparison there is presented in Table 2 a summary of analyses made on some of the commonly used leguminous and non-leguminous hays.

Before discussing the data in Table 1, we must point out that certain anomalies appear, which, although inexplicable, need to be included, if for no other reason than that we cannot account for them. For instance, the two samples gathered on September 16 were unaccountably low in protein and ash and high in fibre. The analyses of these particular samples were repeated and they checked. It should be kept in mind that a carefully planned growing experiment, with replication to eliminate variation due to soil and other environmental factors, would be difficult to carry out, because it requires drought conditions to make this plant flourish typically. Consequently this study was more or less fortuitous and it was necessary to get material where it could be obtained. As much care as possible was exercised to select plants at various stages of growth, but it was not always

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possible to find them growing within a small area. A record was kept of the general type of soil on which they grew so that they could be segregated into two classes, those from heavy soil and those from light soil. Despite these shortcomings, the data here presented seem to justify certain conclusions regarding the composition of Russian thistle which may be of interest.

Table 1 shows that the plants at the flowering stage were exceedingly high in ash, quite high in protein, and relatively low in crude fibre. With advancing maturity, there was a very marked reduction in relative ash content, a moderate decrease in protein content and increases in crude fibre and fat. The nitrogen-free extract remained almost unchanged over the 78-day period. Probably the change in ash content is the most important. It has been supposed that the high ash was responsible for the "scouring" that follows the extensive feeding of Russian thistle. The reduction of ash content with maturity is consistent with observations that older plants cause less scouring than young plants.

Although there was a marked increase of crude fibre content with maturity, the highest values are about the same as for alfalfa and sweet clover and somewhat lower than for non-leguminous roughages such as timothy, western rye grass and red top hays, which according to our analyses average about 34% crude fibre.

TABLE 1.—COMPOSITION OF THE DRY MATTER OF RUSSIAN THISTLE AT VARIOUS STAGES OF GROWTH

Date of cutting	No. of samples		Percentage composition on moisture-free basis				
			Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
July 31—Early flowering	5	Max.	18 6	20.7	25.9	2.3	47.0
		Min.	14.7	10.4	21.4	1.5	38.2
		Average	16.7	15.4	23.5	1.9	42.5
August 7	4	Max.	18.2	23.3	19.0	1.9	50.1
		Min.	8.9	20.9	17.4	1.7	37.5
		Average	14.7	22.1	18.2	1.8	43.2
August 26	2	A	16.8	22.4	20.5	2.1	41.8
		B	16.5	18.8	17.9	1.7	41.5
		Average	16.7	20.6	19.2	1.9	41.7
September 16	2	A	10.7	28.7	13.6	3.8	43.9
		B	10.4	28.6	13.6	3.3	43.4
		Average	10.5	28.6	13.6	3.6	43.6
September 23	2	A	14.7	25.8	16.1	5.8	41.6
		B	12.2	23.0	15.6	4.9	40.4
		Average	13.4	24.4	15.8	5.4	41.0
October 5	2	A	15.3	28.8	13.7	5.6	38.7
		B	14.7	27.6	12.7	5.1	37.7
		Average	15.0	28.2	13.2	5.3	38.2
October 18—Fully mature	2	A	14.4	29.4	11.8	5.3	42.7
		B	13.6	25.8	9.7	5.3	42.1
		Average	14.0	27.6	10.8	5.3	42.4

TABLE 2.—SUMMARY OF ANALYSES OF HAYS PRODUCED IN VARIOUS LOCALITIES OF NORTHERN SASKATCHEWAN*

Variety	No. of samples		Percentage composition on moisture-free basis				
			Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
		Max.	22.6	36.1	12.8	3.8	46.1
Alfalfa	18	Min.	14.8	24.9	7.6	1.9	33.1
		Average	16.2	29.4	9.9	2.6	40.3
		Max.	22.4	38.9	13.0	3.7	46.7
Sweet clover	16	Min.	14.1	20.8	7.1	1.8	35.4
		Average	17.5	27.8	10.3	2.6	41.8
		Max.	9.2	42.4	9.1	3.2	53.4
Timothy	7	Min.	6 8	28.6	5.1	2.0	40.0
		Average	8 2	32.6	6.8	2.5	49.8
		Max.	12.6	36.0	9 4	3.5	46.2
Western rye grass	5	Min.	9.2	32 4	5.2	2.9	42.3
		Average	10.9	34 7	6.7	3.2	44.4
		Max.	12.3	37 7	10 2	2.7	52.7
Red top	5	Min.	6 8	30.0	5.6	2 2	37.4
		Average	9.4	33.5	7.9	2.5	46.7

* These analyses were made on samples which had been cut and cured at the stage of growth considered best for the production of good hay.

The crude protein content decreased with advancing maturity, but even in ripe plants was markedly higher than in non-leguminous hays but somewhat lower than in leguminous hays. The values are roughly: legume hay 17%, Russian thistle 14%, and non-leguminous hays 9.5%. Plants harvested in the flowering stage and cured would have a protein content averaging practically the same as alfalfa.

The nitrogen-free extract, which is an estimate of the soluble and easily hydrolyzable carbohydrates, showed little variation over the growth period investigated. The values average about 42% and are about the same as for alfalfa, sweet clover and western rye grass, hays which were found to be 40.3, 41.8 and 44.4% respectively; they are somewhat lower than that of timothy and red top hays.

On the basis of composition alone, mature Russian thistle compares favourably with alfalfa hay in all components. It would not, however, be suggested that they are equal in feeding value, because the spiny nature of the dry plant makes it objectionable and it is generally recognized that it is rather unpalatable. Esplin, Greaves and Stoddart (1) estimate its palatability for sheep at 30–40 (100 for maximum palatability). However, animals on restricted rations will eat Russian thistle quite readily and it is interesting to know how favourably it compares with the standard forages in composition.

These data also indicate how the wide difference in various reported analyses, summarized by Walker (3), may be reconciled. It seems probable that these differences result from taking the plant at different stages of maturity.

Effect of Soil on Composition of Russian Thistle

In view of some of the irregularities shown in Table 1, it was thought desirable to find what effect, if any, different soil types might have on the composition of the plant. Accordingly, five samples were obtained from each of two distinct soils, a clay loam and a sandy loam soil. The analyses of these samples are summarized in Table 3.

TABLE 3.—THE EFFECT OF SOIL TYPE ON COMPOSITION OF RUSSIAN THISTLE

Soil type	No. of samples		Percentage composition on moisture-free basis				
			Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
		Max.	18.6	20.8	25.9	2 3	47.0
Clay loam	5	Min.	14.7	10.4	21.4	1.5	38.2
		Average	16.7	15.4	23.5	1.9	42.5
		Max.	18.4	23.3	23.0	1 9	50.1
Sandy loam	5	Min.	14.5	16.5	17.4	1.7	37.5
		Average	15.4	21.0	19.2	1.8	42.6

Although the nature of the sampling does not warrant any hard and fast conclusions, the data in Table 3 indicate that plants grown on the heavier soil were lower in crude fibre and higher in crude ash than those grown on the lighter soil. The other components showed no appreciable differentiation. Low fibre and high ash are characteristics of the more immature plants and the values obtained with plants grown on the heavier soil might be accounted for by assuming that this soil had more available water in it than the light soil and that the ripening of the plants was therefore retarded. The greatest care possible, however, was exercised in gathering the samples to get them at similar stages of growth from each soil and we conclude therefore that the heavier soil is likely to produce Russian thistle plants of higher ash content than light soils.

Comparison of Plants of Different Sizes

Russian thistle plants vary greatly in size. Those growing in patches, thickly seeded, suffer from heavy competition and tend to be spindly and short even when mature, while those not checked by competition become extremely branchy and may attain a height of 2 feet and a diameter of 3 feet. A question arose concerning the composition of the dwarfed and the luxuriant plants. Some of the data already tabulated were rearranged on this basis. The average values for the two classes of plants did not justify the conclusion that they are differentiated.

Composition of Tops, Crowns and Roots

The common practice is to cut Russian thistle with the mower, but in some circumstances the growth on summerfallow or other cultivated land has been such that this has not been practicable and the cultivator or rod-weeder has been used. Plants harvested in this manner have most of the

root adhering and it was necessary therefore to get some idea of the effect on feeding value of including the roots. Samples of tops, crowns and roots from one lot of plants were prepared and analysed.

TABLE 4.—COMPOSITION OF TOPS, CROWNS AND ROOTS OF RUSSIAN THISTLE

—	Percentage composition on moisture-free basis				
	Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
Tops	18.4	16.5	23.0	1.8	40.3
Crowns	7.4	40.2	11.5	0.7	40.5
Roots	7.2	45.3	7.8	0.6	39.0
Oat straw (2 analyses)	5.2	43.1	7.8	2.0	41.8

It can be seen from Table 4 that the crowns and roots are much lower than the tops in respect to crude protein and crude ash, very much higher in fibre and about the same in nitrogen-free extract. Inclusion of the roots would therefore lower the feeding value of the material. It is interesting to note, however, that the composition of the roots of Russian thistle compares favourably with the composition of oat straw which is frequently used as a roughage.

SUMMARY

Analyses of Russian thistle collected at various stages of growth from early bloom to complete maturity showed that with advancing maturity there is a marked reduction in ash content, some reduction in protein content, an increase in fat and fibre and little change in nitrogen-free extract. At maturity the composition of the plant is not much different from that of alfalfa hay.

Samples from clay loam soil were higher in ash and protein and lower in fibre than those from sandy loam soil.

The crowns and roots of the plant are very much lower in protein and ash and very much higher in fibre than the tops. The roots are similar to oat straw in composition.

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A PRELIMINARY INVESTIGATION OF THE VALUE OF CORN DISTILLERS' DRIED GRAINS IN CHICK RATIONS[1]

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[Received for publication, April 28, 1938]

INTRODUCTION

Because of the expansion of the distilling and brewing industries during the past few years, their by-products, such as distillers' grains, brewers' grains and so forth, have tended to accumulate on the market. The amount of these products available during prohibition years was not large and little research with regard to their feeding value was done. This is especially true of poultry feeding, since the majority of the formulae for poultry rations now in use have been developed during the past ten years. At the time this research was done, these by-products were relatively cheap being quoted at 1 to 1½ cents per pound. If they can be used satisfactorily in chick rations they would tend to lower the cost. In so far as the authors are aware, no experimental work has been done with regard to the value of distillers' dried grains in chick ration, but since the completion of this work, Insko, Buckner, Martin and Harms (2) and Buckner, Insko, Martin and Harms (13) have studied the value of distillers' dried grains and distillery slop in growing and fattening rations.

In the manufacture of alcohol and distilled liquors from cereals, the corn, rye or barley, after being ground is treated with a solution of malt to convert the starch into sugar, which, in turn, is converted into alcohol by the action of yeast. The alcohol is distilled off, leaving a watery residue known as distillers' slops. The solid matter is usually drained out and dried in vacuum, forming dried distillers' grains or distillers' dried grains, which are sold. This by-product consists of the portions of the grain not acted upon during the fermentation process, that is, the crude protein, fibre, fat and the more insoluble part of the nitrogen-free extract. In addition, it contains appreciable amounts of the yeast formed during the fermentation. As there is a difference in the composition and livestock feeding value of distillers' grains produced from different grains, they are usually called corn distillers' dried grains[4] or rye distillers' dried grains, depending upon which grain predominates. It would appear that the nutritive value of these grains in poultry rations may depend not only upon their protein or mineral content but probably includes their content of the vitamin B complex.

Corn distillers' dried grains contain from 28 to 32% crude protein, averaging about 30%, with from 9 to 11% fat and about 11% fibre. According to Morrison (17) they furnish 85 pounds of total digestible nutrients per 100 pounds, which is more than supplied by such feeds as

[1] This work formed the undergraduate thesis of one of the authors (R.T.A.) submitted in fulfilment of the requirements for the degree of Bachelor of Science of Agriculture, 1936.

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[4] There appears to be some difference of opinion as to the correct name of these feeds. We have used the term "corn distillers' dried grains" since it is the name used in The Feeding Stuffs Act, 1937, and in the official publication of the Association of American Feed Control Officials, 1936. On the other hand, Morrison (15) refers to this product as "Distillers' corn dried grains" and the terms "dried distillers' corn grains" or "distillers' dried corn grains" are also in use.

corn, corn gluten feed, linseed meal or cottonseed meal. He further states that they are "deservedly a popular feed for dairy cattle," but points out that because of their bulkiness they should not comprise more than 15 to 20% of the ration for pigs. Although the question of the digestion and utilization of crude fibre by poultry is by no means settled, as pointed out by Mangold (15), the above statement probably holds true also for poultry.

As Halpin and Holmes (7) and Halpin, Holmes and Hart (8, 9) have shown that rye is not a satisfactory grain for chicks, corn distillers' dried grains were used in this preliminary experiment. This product analyzed 5.3% moisture, 31.4% crude protein (N $\times$ 6.25), 5.0% fat, 13.1% crude fibre and 1.3% ash. Previous experiments in this laboratory, Stephens (19), indicated that corn gluten feed could be satisfactorily used as a part of the protein supplement in chick rations. Hence, it was considered that the protein in corn distillers' dried grains might also be valuable. In order to obtain some information with regard to the vitamin B complex, dried brewers' yeast and wheat germ, which are known to be good sources of this complex, were compared with the distillers' grains.

The term "vitamin B complex" is used to designate a group of water soluble vitamins. This group includes B_1 or B (antineuritic), B_2 or G or flavin (growth promoting), B_3 (pigeon weight maintenance, possibly required by the chick), B_4 (rat growth and required by the chick), B_5 (pigeon growth factor), B_6 (rat antidermatitis), and several others. Vitamin B_2 has been used by some workers to designate the heat stable fraction of the vitamin B complex. If this terminology is used, then vitamin B_2 must be considered as itself consisting of several factors. At the present time it is also impossible to correlate the requirements of various types of "experimental animals" for the various fractions of the vitamin B complex.

Although poultry require vitamin B_1 in order to prevent avian polyneuritis, it is present in the germ and bran of all grains. Since grains and their products constitute a large part of poultry rations, this vitamin should not be deficient in ordinary rations, unless they have been heated. Vitamin B_2 (G) as originally postulated in poultry nutrition was a complex. The term vitamin B_2 or G is now, with few exceptions, used to designate riboflavin (lactoflavin or hepatoflavin) which is required by poultry for growth and is an important factor in hatchability. Chicks also require some part of this complex in order to prevent the onset of nutritional paralysis, a disease in which the birds walk on their hocks with the toes characteristically curled inward. The bulk of the evidence indicates that this nutritional paralysis is caused by a deficiency in flavin, but there is some evidence that a separate factor is involved. Riboflavin is furnished in poultry rations by milk, whey, liver, grass, alfalfa, etc.

Riboflavin has no effect on chick dermatitis (pellagra). For a time it appeared that two factors were concerned in chick dermatitis. This confusion arose through the similarity in the appearance of the symptoms produced in chicks as a result of egg white feeding, and the dermatitis produced by feeding a heated diet of natural foodstuffs. It is now established that the egg white syndrome has an entirely different etiology from the heated diet dermatitis and that chick dermatitis is caused by a deficiency of one factor, variously referred to as the antidermatitis, antipellagric or Factor 2 of the filtrate factor (generally spoken of as "the filtrate factor").

The chick antidermatitis factor is quite distinct from the factor (B_6 or Factor 1 of the filtrate factor) which prevents dermatitis in rats or that which prevents pellagra in humans (nicotinic acid). It is also growth-promoting in chicks.

A deficiency of vitamin B_4 in poultry rations results in lowered growth, inco-ordination and paralysis. In the earlier work this paralysis was confused with nutritional paralysis and it was considered also that it was identical with nutritional encephalomalacia. These are considered now to be three separate and distinct abnormalities. It is doubtful if chicks require B_3, B_5, or B_6.

These water-soluble factors of the vitamin B complex appear to have a common characteristic in that they all occur in yeast. There has been considerable controversy as to whether the usual type of poultry rations which contain considerable quantities of cereal grains or their products, are improved by the addition of yeast, usually added as dried brewers' yeast.

Dougherty (3) stated that the addition of pure dried granulated yeast to a standard ration stimulated appetite and materially increased the growth rate even when chicks were fed liberal amounts of green feed. Mussehl and Ackerson (18) concluded that the growth rate of chicks was increased by the addition of yeast to certain chick rations which contained at least 75% of cereal products. The improved growth rate may have been due either to protein or to vitamin B_2 contributions. Gerhardt (4) also reported that the addition of 3% yeast to a normal ration resulted in better food consumption and growth.

Hamilton, Cark and Kick (10) concluded that a ration for growing chicks containing 60% of ground whole grains (corn, oats and wheat) and 20% of other seed products was apparently not deficient in vitamin B. For chicks reared under laboratory conditions there was a suggestion, however, that the addition of yeast enhanced the nutritive value of the ration.

On the other hand, Bethke and Kennard (1) stated that a ration containing 63% or more of whole grains (corn and wheat) and 10% of other seed products (soyabean oil meal and wheat bran) and 20% of either meat scraps or dried buttermilk, with adequate mineral and fat-soluble vitamin supplements, was found to meet the vitamin B requirement of growing chicks kept for ten weeks on wire floors.

There are certain possibilities for this variation in the results of supplemental yeast feeding. First, there would undoubtedly be a difference in the amounts of the various fractions of the vitamin B complex furnished by the basal diets. Vitamin B_2 (riboflavin) and the chick antidermatitis factor, although these latter are furnished to some extent by cereal grains, are probably the fractions involved. Secondly, there is a variation in the vitamin content of various types and strains of yeast, dependent to a considerable extent upon the culture media. Thirdly, there is the probability that yeast alone does not furnish all the water-soluble factors required by chicks. Experiments conducted in this laboratory, Graham, Pettit, Sykes and Howell (6) and van der Hoorn (20) and elsewhere, Hogan and Shrewsbury (12), have shown, by the use of simplified diets, that,

when used as the sole vitamin B complex supplement, it required about 30 to 40% dried brewers' yeast or about 30% wheat germ to meet these requirements. On the other hand, a combination of 10 to 15% yeast with 10% wheat germ gave more satisfactory results. Hogan and Boucher (11) and Keenan, Kline, Elvehjem, Hart and Halpin (14) have used various extracts of liver to supplement the yeast in such diets. It is possible that some supplementary effect between the various factors in the vitamin B complex or a deficiency in some factor of this complex may also be involved.

McConachie, Graham and Branion (16), to whom the reader is referred for a review of similar investigations, concluded that the optimum amount of crude protein in a ration for growing chicks to 12 weeks of age was approximately 19%.

EXPERIMENTAL

The composition of the various rations fed, together with their approximate analyses is shown in Table 1. Thirty newly hatched Barred Plymouth Rock chicks were started on each ration. The birds were kept indoors in single tier, wire floored, battery brooders. They were individually weighed

TABLE 1.—COMPOSITION OF RATIONS (Pounds)

Ingredients	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Diet 7	Diet 8	Diet 9	Diet 10
Ground yellow corn	25	25	25	25	25	25	25	25	20	25
Ground wheat	25	25	25	25	25	25	25	25	20	25
Ground oats	25	25	25	25	25	25	25	25	20	25
Ground barley	25	25	25	25	25	25	25	25	20	25
Alfalfa meal	5	5	5	5	5	5	5	5	5	5
Fish meal	5	5	5	5	5	5	5	5	5	4
Meat meal	5	5	5	5	5	5	5	5	5	4
Dried buttermilk	5	5	5	5	5	5	5	5	5	5
Dried brewers' yeast		5						2½		
Wheat germ			5	10			5	5		
Corn distillers' dried grains					5	10	5		20	5
Bone meal	1	1	1	1	1	1	1	1	1	1
Oyster shell	2	2	2	2	2	2	2	2	2	2
Salt	½	½	½	½	½	½	½	½	½	½
Cod liver oil	1	1	1	1	1	1	1	1	1	1
Per cent crude protein (N × 6.25)	16 4	17 5	16.8	17 1	16 8	17.1	17.1	17 3	18.8	16.1
Per cent crude fibre	5.5	5.3	5.3	5 2	5.8	6.1	5.6	5.3	6.9	5.9
Per cent ash	7.3	7 4	7.2	7.4	7.2	7.1	7.1	7.3	7.5	6.9

each week to the nearest gram and at the end of the experimental period of 10 weeks, they were examined for percentage feathering over the back. Feed consumption was recorded. The chicks were allowed unrestricted access to insoluble grit.

The ration fed to Group 1 was a "chick starter" ration which has been used with reasonable success at the Department of Poultry Husbandry. It is not a high protein ration and hence does not grow chicks quite as rapidly as some rations, but considered over the whole growth period, its use results in birds which compare very favourably with most similar rations. This group served as a control. In Group 2 this ration was supplemented with 5 pounds of dried brewers' yeast which raised the crude

protein content about 1%. It is doubtful if this increase in protein content, or the difference in protein content between any of these rations, is sufficient to cause any difference in growth response. Since the brewers' yeast contained about twice as much crude protein as the wheat germ or the distillers' grains, the ration of Group 3 was supplemented with 5 pounds of wheat germ and that of Group 4 with double this quantity in order to furnish approximately the same amount of protein. Similarly the rations of Groups 5 and 6 were supplemented with 5 and 10 pounds, respectively, of the corn distillers' dried grains. The ration of Group 7 was supplemented by a combination of 5 pounds of wheat germ and 5 pounds of distillers' grains and that of Group 8 by a combination of 2½ pounds of yeast and 5 pounds of wheat germ. In the ration of Group 9, twenty pounds of distillers' grains were used to replace 5 pounds each of wheat, corn, barley and oats. In the ration of Group 10, five pounds of distillers' grains were used to replace one pound each of the fish and meat meals.

A comparison of the results of Groups 2, 3 and 5 should show the relative value of equal quantities of yeast, wheat germ and distillers' grains, respectively, in supplementing the control ration (Group 1); while a comparison of Groups 2, 4 and 6 should show the relative value of the quantities of these three supplements supplying the same amount of protein. The results with Groups 7 and 8 should check the supplementary value of wheat germ and distillers' grains against yeast and wheat germ, with the total protein content of the rations approximately the same. Group 9 should give some indication of the value of distillers' grains as a cereal supplement, since, at its current price, it could compete with cereal grains, in addition to supplying 2 to 3 times the protein. In Group 10 an attempt was made to obtain some idea of the value of this protein in distillers' grains.

Since dried buttermilk is an excellent source of flavin, as well as containing some of the other factors in the B complex, its amount in these rations was not varied, in order to remove, in so far as possible, this complicating factor. No attempt was made to equalize the total ash content of these rations, but the variation does not appear to be appreciable.

The average weekly weights and the number of birds surviving at each weighing are shown in Table 2. The average weight of each group with the average weight of the cockerels and pullets in each group at 10 weeks of age, the percentage feathering over the back for each sex, the feed-gain ratio, the number of chicks with deformed legs (including bending, bowing and perosis) and the mortality are shown in Table 3. In calculating the feed gain ratio, or number of pounds of feed required to produce a pound gain, mortality is charged against the ration.

DISCUSSION

The growth response of Groups 2, 3, 4, 5, 6, 7 and 8 as compared to that of Group 1 indicated that supplementing the control diet with either yeast or wheat germ or corn distillers' dried grains or with a combination thereof, resulted in improved growth. As was pointed out, the greatest amount of additional protein furnished by any of these supplements was 1.1% over that of the control diet. It therefore would appear probable that the greater part of this extra growth, which with one exception (Group

6) was associated with more efficient food utilization, was due to some factor in these supplements, presumably in the vitamin B complex. In other words, feeding additional vitamin B complex was beneficial to chicks reared under laboratory conditions, in spite of the fact that a large part of the control ration consisted of cereal grains.

TABLE 2.—AVERAGE WEEKLY WEIGHTS (Grams)

Group	Weeks										
	0	1	2	3	4	5	6	7	8	9	10
	30*	30	29	27	26	26	26	26	26	26	26
1	34	62	87	124	157	226	291	383	494	600	697
	30	30	30	30	30	30	30	30	30	30	30
2	36	64	98	152	215	311	374	500	615	757	861
	30	30	27	25	25	25	25	25	25	25	25
3	34	65	93	135	181	274	354	457	574	696	822
	30	30	28	24	24	24	24	24	24	24	24
4	35	67	98	137	191	280	344	475	603	746	880
	30	30	29	28	28	28	28	28	28	28	28
5	31	65	97	144	197	283	365	487	618	757	857
	30	30	27	24	24	24	24	24	24	24	24
6	36	66	89	130	180	251	318	430	550	671	810
	30	30	29	29	29	29	29	29	29	29	29
7	33	73	98	152	209	301	345	473	591	714	852
	30	30	29	28	28	28	28	28	28	28	28
8	36	71	103	155	216	304	367	489	606	731	860
	30	30	30	30	30	30	30	30	30	30	30
9	36	66	96	148	198	300	367	478	592	731	859
	30	30	30	29	29	29	29	29	29	29	28
10	37	65	93	133	180	257	330	435	550	664	813

*Number of chicks surviving each week.

TABLE 3.—SUMMARY OF RESULTS AT TEN

Group	Average weights			Feathering		Feed : Gain Ratio	Deformed legs	Mortality
	Group	Cockerels	Pullets	Cockerels	Pullets			
	grams	grams	grams	%	%		chicks	chicks
1	697	712	673	28	48	3.77	2	4
2	861	941	792	50	85	3.17	0	0
3	822	879	783	19	50	3.47	0	5
4	880	967	793	40	88	3.26	0	6
5	857	926	751	40	67	3.49	1	2
6	810	829	793	56	79	3.89	0	6
7	852	966	782	33	64	3.47	0	1
8	860	974	775	37	85	3.59	3	2
9	859	877	817	30	79	3.36	1	0
10	813	893	720	48	83	3.70	0	2

A comparison of the differences between the average weights of Groups 2, 3, 4, 5, 6, 7 and 8 with studies conducted under similar conditions in this laboratory indicated that there was no significant differences between the average weights of the birds in these groups. A difference of 100 to 150 grams is necessary for significance. No beneficial effect of combining these supplements in comparison to their individual use was evidenced.

The response of Group 9 would indicate that, within reasonable limits, at least to 20%, corn distillers' dried grains may be used satisfactorily to replace part of the cereal grain mixture in chick rations. The response of Group 10 would suggest that the protein in distillers' grains is worthy of further study, as a replacement for a part of the "animal" protein in such rations.

It will be observed from Table 3 that the percentage of feathering over the back has been improved, with the exception of Group 3, by the addition of these supplements to the ration. Although 5% wheat germ gave no improvement, increasing this supplement to 10% resulted in more feathering than the control group. Similarly, although 5% distillers' grains (Group 5) resulted in feathering superior to that of the controls, the addition of 10% (Group 6) gave more improvement.

Gerrick and Platt (5) found that feather development in Barred Plymouth Rock chicks was improved proportionally with increasing amounts of protein, up to the optimum, in the ration. McConachie, Graham and Branion (16) found a general relationship between feather development and the protein content of the diet, but suggested that the optimum protein level for growth was not necessarily the optimum protein level for best feather development. Both low and high protein levels upset the barred feather pattern. The protein of a ration is not the only nutritive factor concerned in feather development. There is evidence that the vitamin B complex is also concerned. It is probable, that other factors being equal, the nearer optimum the ration is in all nutritive factors, the better will be the feather development.

The severity of the deformed legs was slight in the few cases which did occur.

It should be borne in mind that the beneficial results in this preliminary investigation seem to be due chiefly to the additional vitamin B complex furnished by corn distillers' dried grains, dried yeast or wheat germ, but there is no strict proof. The results may have been due to other factors, such as minerals, or to a combination of such factors. Strictly speaking, this experiment only shows that under the conditions of this test, the addition of these supplements to the basal ration resulted in some improvement. Since yeast and wheat germ are known to be good sources of the vitamin B complex, one is inclined to consider that this group of vitamins was responsible for the improvement.

SUMMARY

The addition of wheat germ, dried brewers' yeast or corn distillers' dried grains, either singly or in combination, to an ordinary ration with the usual amount of cereal grains, fed to chicks under laboratory conditions, improved growth and feather development. This increased growth was

associated in general, with more efficient utilization of food. This improvement would appear to be associated with the additional amounts of the vitamin B complex furnished by these supplements.

These results, although preliminary, indicate that under confined conditions, the ordinary types of chick rations may be improved by additional vitamin B complex supplements. Corn distillers' dried grains would seem to be a reasonable source of this complex.

ACKNOWLEDGMENT

We are indebted to the Maple Leaf Milling Company, Toronto, for the wheat germ and to Hiram Walker and Sons, Windsor, for the corn distillers' dried grains used in this experiment.

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THE MORPHOLOGY AND COMPOSITION OF SASKATCHEWAN PODZOLIC SOILS[1]

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[Received for publication, May 2, 1938]

The four major soil zones of Saskatchewan have been established on the basis of regional soil profiles which reflect the broad differences in climate and vegetation found throughout the province (13). The most northerly soil region so far investigated is known as the gray soil zone and is characterized by gray (podzolic) soils, a wooded (forest) vegetation and a cool sub-humid climate.

The present study is concerned with the more important soil profiles encountered in the southern portion of the gray soil zone and in the transition belt between the gray and black soils. The investigation covers the morphology, composition and environmental features of Saskatchewan podzolic soils, and also serves to illustrate the natural conditions found in the newly settled areas of the province. The field studies of the wooded soils were carried out in conjunction with the work of the Saskatchewan soil survey, a co-operative project of the Dominion and Provincial departments of agriculture. During the course of the survey a large number of soil profiles were examined, and certain representative types were sampled for laboratory study. The chemical data presented represent percentages of soil constituents as determined by methods of total analysis, expressed on a moisture free basis.

DESCRIPTION OF THE AREA

Location and Extent.

The province of Saskatchewan extends from 49° to 60° North latitude and from about 101° 30′ to 110° West longitude. Approximately 150,000 square miles, or 60% of the total area, is included in the gray soil zone, which extends into the Pre-Cambrian region of northern Saskatchewan. No soil investigations have yet been made in the latter region. The area covered by the present study lies along the southern borders of the gray soil zone, roughly between 52° and 53° 40′ North latitude.

Surface Features

The surface topography ranges from nearly level to rolling and hilly, and the altitude varies from 1100 to 2200 feet above sea level. The slope is mainly to the northeast and most of the area is drained by the Saskatchewan river and its tributaries, whose waters ultimately flow into Hudson bay.

Local drainage of upland areas is usually adequate, and may be excessive on soils of rough topography or light texture. The lower lands and depressions are frequently poorly drained, and contain many lakes and peat bogs.

[1] This paper is based upon a thesis submitted to the University of Alberta in partial fulfilment of the requirements for the degree of Master of Science, and also upon the subsequent studies at the University of Saskatchewan.

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The surface geology consists chiefly of glacial morainic, lacustrine and alluvial deposits, the latter occasionally modified by wind action. Recent deposits are represented by peat bogs and shallow marshy areas.

Climate

The climate of the area is typical of north temperatue continental regions, and is characterized by relatively low precipitation and by wide extremes in temperature. Meteorological data are incomplete, but such records as are available indicate an average annual precipitation of about 15.5 inches, an average annual temperature of 30° to 31° F., and a frost-free period of approximately 100 to 110 days.

Vegetation

The vegetation of the wooded region is predominantly a forest cover of trees and shrubs. The southern part of the region, bordering the black soil zone, is covered chiefly with deciduous trees, largely aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) with some canoe birch (*Betula papurifer*). Some coniferous trees also occur, notably jack pine (*Pinus Banksiana*), white spruce (*Picea Canadensis*) and tamarack (*Larix Americana*). Numerous shrubs are also common such as willows (*salix* spp.), hazelnut (*Corylus rostrata*), dogwood (*svida instolonea*), wild cranberry (*viburnum opulus*), alder (*Alnus incana*), Saskatoon berry (*Amelanchier alnifolia*). In the muskegs or bogs, marsh grasses, sedges (*Carex* spp.) sphagnum moss, and Labrador tea (*Ledum groenlandicum*) are found, often in association with small spruce and tamarack. In the more northerly portion of the province coniferous trees predominate, although the aspen and poplar are common to the whole of the forest region.

Soils

The soils of the area may be placed in two main groups: podzolic upland types, and peat soils of poorly drained positions. The podzolic soils vary in morphological character from slightly degraded black soils to well developed ashy-gray podzols. These profile variations are related to differences in parent materials, topographic position and vegetative cover, the more strongly leached soils being associated with well drained positions and medium to light textured parent materials.

The most extensive of the podzolic upland soils are those developed on glacial till and morainic deposits under a forest cover of deciduous trees and occasional clumps of spruce. Other profiles encountered are podzolic fine sands on alluvial deposits, chiefly under jackpine vegetation, and degraded black soils on heavy lacustrine deposits. Small areas of degraded black soils are also found on glacial till and sandy alluvial materials. The degraded black soils are transitional types between the black and gray soil zones and also occur as islands within the gray soil zone itself.

The peat soils vary in depth of the raw peat layer, reaction, and nativ vegetation. High lime peats are most common, occurring under sedge and marsh grasses. The more acid peats are associated with a sphagnum and tamarack vegetation, but even these are alkaline in the lower horizons. Calcareous black soils and podzolic peats are sometimes found around the borders of the marshes and bogs.

Agriculture

The agricultural development of the area is closely related to the natural factors discussed above, and in particular to the soil type. The degraded black heavy lacustrine soils are the most productive, followed by the lighter textured degraded soils. The podzolic glacial types are less fertile, and require good management and special crops to ensure satisfactory development. The podzolic sands are non-arable soils, while very few of the peat areas have been brought under cultivation to date. The factors responsible for these variations in productive capacity are indicated by the following data, and are also discussed in the latest soil survey report (13).

MORPHOLOGY AND COMPOSITION OF SOIL PROFILES

Profile No. 1

Located near Sturgis, Saskatchewan. Podzolised loam on glacial till deposits. Undulating to gently rolling in vicinity, with heavy stand of aspen.

A_0	0 – ½″	Black raw humus layer.
A_1	½ – 4″	Gray loam, coarse and gritty; faint platy structure, easily crushed.
A_2	4 – 8″	Ashy gray loam, similar to above, but with less organic matter.
B_1	8 – 18″	Gray brown heavy clay loam, gritty; compact, breaking into angular fragments.
B_2	18 – 22″	Dark brown clay, stony; compact, nutty to coarse granular structure.
C_1	22″+	Light gray heavy loam, stony; fine granular structure, calcareous.

CHEMICAL ANALYSIS OF PROFILE NO. 1.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	7.76	29.50	1.07	.097	53 05	8 44	2.30	—	7.1
A_1	0.70	2 82	.081	.033	80.20	10 93	1.16	—	6 9
A_2	0.72	1.70	.046	.021	79 04	12 25	0.84	0	7 0
B_1	2.34	2.60	.062	.026	75 60	15.74	1.10	0	6.7
B_2	3.10	2.16	.053	.044	70.50	16.88	1.40	0.29	7.0
C_1	0.70	1.34	.020	.042	62 25	14.25	4.96	7 23	8 1

Profile No. 2

Located near Crooked river. Podzolised heavy loam on glacial till. Undulating upland topography, aspen vegetation, with willow and spruce in low areas.

A_1	0 – 1″	Grayish black mixed organic and mineral layer, true A_0 having been destoyed by fire.
A_2	1 – 8″	Ashy gray heavy loam, gritty. Faintly platy, easily crushed.
B_1	8 – 14″	Coffee brown clay. Compact, breaking to coarse hard granules. Slightly calcareous.
B_2	14 – 18″	Brown to yellow-brown clay, stony. Structure as above. Calcareous.
C_1	18 – 55″	Dark gray clay, gritty. Coarse granular, calcareous.

CHEMICAL ANALYSIS OF PROFILE NO. 2.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_1	2.00	8.80	.341	.100	72.40	9.71	1.76	—	7.5
A_2	1.39	1.98	.067	.050	80.30	12.91	0.95	—	6.8
B_1	3.54	4.56	.071	.050	67.82	15.91	1.24	0.36	7.7
B_2	2.78	4.19	.069	.033	61.22	15.43	4.03	5.04	8.0
C_1	2.00	3.53	.040	.041	54.94	12.63	7.63	10.96	8.1

Profile No. 3

Located near St. Walburg. Podzolised light loam on glacial till. Undulating upland topography, with heavy stand of aspen. Lower land is either muskeg with spruce and various shrubs, or low sand ridges with jackpine vegetation.

A_0	0 – 2″	Black raw humus layer.
A_1	2 – 2½″	Dark gray fine sandy loam, structureless. Mineral soil high in humus.
A_2	2½ – 7½″	Ashy gray light loam (silty). Powdery structureless layer.
B_1	7½ – 13″	Dark gray-brown clay. Compact, coarse granular structure.
B_2	13 – 36″	Dark gray clay with small stones. Compact, breaking into coarse granules.
C_1	36″+	Dark gray clay, granular, calcareous.

CHEMICAL ANALYSIS OF PROFILE NO. 3.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	5.34	32.80	1.55	.114	54.23	6 00	2.19	—	7.3
A_1	1.22	4.90	.186	.031	82.82	8.31	0.91	—	7.3
A_2	0.62	1.21	.030	.012	84 91	8 64	0.70	0	6.9
B_1	1 90	3.02	.050	.018	79.06	14.46	0.75	0	6.5
B_2	1.85	4 66	.037	.023	79 85	14.34	0.75	0	6.5
C_1	1.24	6.57	.024	.038	76 68	11.13	3.09	3 85	7.8

Discussion of Profiles 1, 2, and 3

The data for Profiles Nos. 1, 2 and 3 illustrate the more important characters of podzolic upland soils developed on glacial till deposits, the most extensive soils of the gray soil zone. The profiles exhibit the following morphological features: a surface layer of partially decomposed organic matter, except where destroyed by forest fires; a dark gray, platy A_1 horizon, which is usually very thin, and is sometimes absent; a strongly leached, ashy gray, A_2 horizon, often platy but easily crushed to a powdery form; the heavier B_1 and B_2 horizons, coffee brown to grayish brown in colour, compact, and breaking into angular fragments or coarse granules; and finally a lighter coloured highly calcareous parent material. The zone of lime carbonate frequently extends into the B horizons.

MECHANICAL ANALYSIS OF PROFILE NO. 3

Horizon	Clay (<.005 mm.)	Silt (.005-.05)	Sand (.05-1.0)
A_1	12.75	36.15	44.48
A_2	15.00	45.25	35.89
B_1	41.25	19.50	40.14
B_2	41.60	19.00	40.06
C_1	33.70	22.45	41.96

The analytical results indicate that these soils have been subjected to the leaching processes associated with podzolic weathering. In all cases the B horizons are higher in total oxides and lower in silica than the corresponding A_1 and A_2 horizons. The calcium content is high in the A_0 and A_1 horizons, lowest in the A_2, and thereafter increases with depth. High amounts of lime carbonate ($CaCO_3$) are frequently found in the lower B horizons, as shown by the figures for CO_2. No free lime was found in any of the A_2 horizons.

The organic nature of the surface layer is indicated by the figures for nitrogen and loss on ignition, which are considerably higher in the A_0 than in the lower horizons. The content of nitrogen is higher in the B_1 than in the A_2 which, with figures of a similar order for hygroscopic moisture and loss on ignition, indicate a movement from the A_2 to the B horizons of both organic and inorganic colloids. The nitrogen content drops sharply in the parent material.

Phosphorus, like nitrogen, is found in greatest amounts in those horizons relatively high in organic matter, except in the parent material, where the phosphorus content is generally higher than that of the lower B horizon.

The pH values indicate that these profiles are slightly acidic to quite alkaline in reaction. The lowest pH values occur in the A_2 and B horizons, and the latter are generally the most acid, unless lime carbonate is present. No serious acidity however, has so far been encountered in the podzolic glacial soils.

The mechanical analysis of Profile No. 3 illustrates the great textural difference between the A and B horizons. A comparison of the clay and silt contents of these horizons suggests that a mechanical downward movement of some of the fine clay fraction has taken place. This is in accord with the chemical data for silica and sesquioxides, and also with the textural properties these soils exhibit in the field.

The foregoing analyses indicate that only slight differences in composition exist between the B_1 and B_2 horizons. The latter are characterized by lower nitrogen and higher pH values than the former, and frequently contain lime carbonate.

Profile No. 4

Located east of Fort a La Corne Forest Reserve. Podzolised fine to very fine sand of alluvial origin, on level well drained land. Aspen and jackpine vegetation.

A_1	0 – 1″	Gray, with faint dark tinge. Fine sand with fairly high humus content, loose and structureless.
A_2	1 – 13″	Gray, fine and very fine sand, loose and structureless.
B_1	13 – 36″	Brown light fine sandy loam, dusted with gray. Hard and compact, nutty to cloddy structure.
B_2	36 – 58″	Gray brown very fine sandy loam. Moderately compact but not as hard as B_1.
C_1	60″+	Yellowish gray fine and very fine sand. Loose and structureless. No lime carbonate present.

PARTIAL ANALYSIS OF PROFILE NO. 4.

Horizon	pH	H_2O	Loss on ignition	Clay <.005 mm.	Silt .005–.05 mm.	Sand .05–1.0 mm.
A_1	6 8	0.82	4.73	6.15	6.85	85 48
A_2	6.0	0.45	2.03	6.10	4.70	87.78
B_1	6.4	0.83	1.94	11.50	2.25	85.00
B_2	5.4	1.39	3.16	19.90	1.95	77.90
C_1	5.6	0 55	1.03	7.55	4.50	89.00

Profile No. 4 represents the finer textured podzolic sands, as shown by the compact, cloddy structure and relatively heavy texture of the B horizons. In the coarser sandy and gravelly types these horizons are but faintly compacted and the profile shows little textural variation.

In accordance with the sandy nature of the parent material and the absence of lime carbonate, Profile No. 4 has been leached more deeply and is more acid in reaction than the podzolic glacial soils. These conditions are indicated by the depth of the A_2 and B horizons, the low pH values, particularly in the lower horizons and the figures for mechanical analysis. The latter indicate a decided downward movement of clay, the B horizons containing between two and three times as much clay as the A_1 and the A_2. It should be noted however that the total amount of colloidal material removed from the A horizons is much less than in the case of the heavier textured podzolic soils. Thus while Profile No. 4 is deeply leached as compared with the heavier types, the severity of leaching is not outstanding in view of the ease of water percolation through sandy soils. Similarly the low pH values are readily accounted for by the low lime content of the sands, such soils frequently exhibiting slight acidity even under semi-arid steppe conditions. A relatively much greater leaching effect is necessary to remove the carbonates from the upper two feet of a highly calcareous loam such as Profile No. 1.

Profile No. 5

Located near White Fox. Peat podzolic very fine sandy loam on alluvial deposits of level topography. Present cover thin grass and small clumps of willows, the original cover of sphagnum peat and spruce having been largely destroyed by fire.

A_0	1 - 2″	Black humus layer, grass vegetation on burnt-over peat.
A_1	2 - 4″	Very dark gray very fine sandy loam, thick platy structure, easily crushed.
A_2	4 - 8″	Dark gray with brown tinge, very fine sand, structureless.
B	8 - 10″	Brownish gray loam (silty), streaks of ferric oxide; granular structure.
	10 - 16″	Rusty gray heavy loam, spots of ferric oxide, slightly platy.
	16 - 21″	Yellow brown very fine sand; structureless.
	21 - 25″	Blue gray to yellow heavy loam, compact, coarse granular.
	25 - 46″	Yellow gray very fine sandy loam, granular; slighlty calcareous.
C_1	46 - 56″+	Light gray very fine sandy loam, structureless; calcareous.

CHEMICAL ANALYSIS OF PROFILE No. 5.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	4 28	20.37	.827	.081	60 68	9.29	1.84	—	7.6
A_1	1 00	2.82	074	.029	80.45	10 52	0 84	—	7.5
A_2	1 00	2.52	.060	.027	80.52	10 10	0.92	—	7.4
B	2.12	2.49	.099	.078	76.47	14.04	0.85	—	7.2
	2.38	2.74	.049	.053	76 16	15.42	0.88	—	7.1
	1.51	1.79	.031	.050	79.55	13.41	0.97	—	7.4
	2.50	2.80	.043	.047	74 85	15.51	1.01	0	7.4
	1.50	2.80	.034	.053	78.05	14.58	1.12	0.29	7.4
C_1	1.30	2.10	.025	.046	71.01	11.60	3.84	4.10	8.2

Profile No. 5 represents a podzolic peat soil modified by recent fires. The original peat cover of between 8 and 12 inches was observed in a nearby clump of spruce trees which had escaped the fire. The upper horizons of the present profile are similar to those of the degraded black sandy soils, the A_1 being well defined and the A_2 being dark gray brown rather than

ashy gray. The lower horizons differ considerably from those of the upland podzolic soils, the mottled colouring, presence of ferric oxide and successive layers of variable textured materials being typical of the poorly drained subsoils of sandy peat depressions.

The chemical analysis supports the morphological data, the relative contents of silica and total oxides in the upper horizons being typical of podzolic soils. In the lower horizons these constituents vary with textural conditions, higher silica and lower sesquioxides accompanying lighter textures. Both nitrogen and phosphorus values show a decided increase in the upper B as compared with the A_2 horizon. The pH values for this profile are surprisingly high, particularly since the carbonates have been completely removed to a depth of two feet, with only moderate amounts present four feet below the surface.

Profile No. 6

Located north of Tisdale. Degraded heavy clay loam (silty), on heavy lacustrine deposits. Undulating upland topography, under a heavy stand of aspen and balsam poplar.

A_0	0 – 2″	Black raw humus layer.
A_1	2 – 7″	Dark gray heavy clay loam (silty), coarse granular structure.
A_2	7 – 11″	Gray-brownish clay loam (silty). Thick platy, crushing to fine granules.
B_1	11 – 24″	Dark gray heavy clay. Compact, breaking into coarse granules.
B_2	24″+	Grayish-white heavy clay. Compact and calcareous.

CHEMICAL ANALYSIS OF PROFILE NO. 6.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	6 50	30 11	1 060	.106	50 13	13 56	1 48	—	6 9
A_1	6 30	6 42	254	052	66 74	19 34	1 04	—	6 6
A_2	2 85	3 00	115	026	76 54	13 81	0 93	—	6 9
B_1	4 78	5 32	084	029	64 50	24 00	0 76	0	7 5
B_2	5 10	5 21	077	055	58 01	22 88	2 98	3 14	8 1

The degraded black soils include a variety of profiles ranging between black and podzolic gray types. Profile No. 6 represents a fairly advanced stage of degradation, but the data given above do not indicate full podzolic development. Compared with the first four profiles the Tisdale soil is characterised by a relatively deep A_1 horizon, high in organic matter and nitrogen, while the A_2 horizon is grayish brown instead of ashy gray. The nitrogen content is higher throughout and decreases with depth as in the normal grassland soils. Nevertheless the great difference in silica and sesquioxide contents between the A_2 and B_1 horizons indicates considerable leaching. This is confirmed by the figures for

MECHANICAL ANALYSS OF PROFILE NO. 6.

Horizon	Clay (<.005 mm.)	Silt (.005–.05 mm.)	Sand (.05–1.0 mm.)
A_1	29.22	41.7	25.42
A_2	28.25	40.25	27.85
B_1	74.35	19.10	6.13
B_2	80.95	17.00	3.63

mechanical analysis, which indicate a very decided downward movement of clay. As in the case of the St. Walburg profile (No. 3) there is a relatively high silt content in the A horizons. It is believed that the heavy texture of the soil and the comparatively recent invasion of the forest cover have prevented the leaching of the degraded soils from proceeding as deeply as in the case of the podzolic glacial and sandy alluvial types. Agriculturally the degraded black soils are more productive than the gray soils.

Profile No. 7

Located west of Nipawin. Podzolic silty loam on heavy lacustrine deposits. Nearly level topography, well drained. Heavy aspen cover. Peat in adjoining low areas.

A_2	0 – 12″	Gray with brown tinge. Loam, silty, with large platy structure, breaking easily to flat nut-like forms and large granules. A_0 and A_1 horizons not present.
B_1	12 – 15″	Brown to grayish brown light clay. Small clod structure, breaking to hard angular coarse granules. A hard compact horizon.
B_2	15 – 42″	Bright yellow brown clay loam. Somewhat larger clods, but less compact than B_1, and with small pores.
C_1	42 – 50″	Gray with slight brown tinge. Heavy clay (silty), coarse granular structure, highly calcareous.

PARTIAL ANALYSIS OF PROFILE NO. 7.

Horizon	pH	H_2O	Loss on ignition	Clay (·005 mm)	Silt (·005-05)	Sand (·05-1·0)
A_2	6.9	1.29	4.33	16.35	42.40	39.10
B_1	6.4	1.96	4.68	28.95	35.65	29.90
B_2	6.8	1.58	2.97	24.55	35.55	40.00
C_1	7.6	2.49	5.64	52.50	35.65	10.86

Profile No. 7 represents a more advanced stage of podzolic leaching on heavy lacustrine soils as compared with Profile No. 6. The somewhat lighter textured parent material of No. 7 may have permitted better percolation of soil water. The more strongly leached condition of this profile is shown by the absence of the A_1 horizon and the greater thickness of the A_2 and B horizons. The lower pH values and the greater depth of the lime layer are also significant. The mechanical analysis indicates a removal of clay and a relative increase of silt for the A_2 horizon, a condition found in the other profiles under discussion.

Profile No. 8

Saskatchewan river, north of Nipawin. Peat profile from muskeg. Taken on long gentle slope above river bank. Tamarack, alder and Labrador tea vegetation. Frozen subsoil layer below 12 inches at time of sampling (June 12).

Surface—Light yellow-brown fresh sphagnum moss.

0 – 10″	Yellow brown raw sphagnum and brown decomposing peat.
10 – 12″	Dark brown decomposing peat, with woody fragments of stems, roots, etc.
12″+	Frozen layer, very dark brown mucky peat, more granular than above, and with fewer woody fragments.

Profile No. 8 represents an acid sphagnum peat under a cover of tamarack trees. The frozen condition of the peat below 12 inches prevented deeper sampling. The profile above the frozen layer was saturated with water. The surface layer of fresh sphagnum is quite acid, but the deeper horizons exhibit only slight acidity. The organic nature of the profile is illustrated by the high values for hygroscopic moisture and loss on ignition.

PARTIAL ANALYSIS OF PROFILE NO. 8.

Depth	pH	H_2O	Loss on ignition
Surface	5.4	—	—
0 - 10″	6.8	11.63	97.14
10 - 12″	6.9	17.20	91.81
12″ plus	6.6	17.50	76.00

The high lime peats are composed of coarser materials developed largely from sedges. These soils are often slightly calcareous at the surface, highly calcareous below and are underlain by calcareous sand and sandy clay deposits.

DISCUSSION

The podzolic nature of Saskatchewan wooded soils is discussed in a number of papers by Joel (4, 5) and in the latest soil survey report (13). The present study shows that the wooded soils exhibit considerable variation in morphology and composition. The variations represent different degrees of podzolic leaching, and the main profile features indicate that podzolization has been the dominant factor in the development of the wooded soils.

These Saskatchewan soils are generally similar to the wooded soils of Alberta. Many of the latter however have developed under a heavier precipitation and are more severely leached. The lime carbonate layer occurs at a depth of four feet or more below the surface, while the pH values and calcium contents are lower than those reported in this study (12). Wooded soils with shallower profiles are encountered in the more northerly portion of Alberta, where the rainfall is lower (14). It is of interest to note that the gray wooded soil zones of Alberta and Saskatchewan, including the Pre-Cambrian region, have a combined area of over 300,000 square miles. Large areas of wooded soils also occur in Manitoba (1). The podzol soils found in other parts of the world are discussed in the works of Glinka (3), Marbut (9) Robinson (11) Joffe (6) and Kellog (7), and these were consulted in making the following comparisons.

The Saskatchewan podzolic soils possess a number of features which differentiate them from the podzol soils of more humid regions. These features are: highly calcareous parent materials, frequent presence of calcium carbonate within the solum, relatively high pH values, and very slight unsaturation, the base exchange complex being dominated by calcium (10). From the above conditions it is evident that these soils are not true podzols according to the prevailing systems of soil classification.

On the other hand Saskatchewan wooded soils exhibit many characteristics common to the true podzol. In the first place it should be remembered that the term "podzol" has been adopted from the Russian school of soil science, where it denoted a morphological feature of certain soils. Glinka states "This term is used to designate soils which have a pronounced and well developed whitish A_2 horizon." (3, page 48). This description fits many of the Saskatchewan podzolic soils.

A study of profiles 1 to 5 presents further evidence of the true podzol state of these soils, as shown by the impoverishment of the A_2 in respect to bases, sesquioxides and organic matter, with a corresponding increase of these constituents in the B horizons. Conversely the A_2 is higher in silica than the B. The low content of calcium in the A_1 and A_2, and the high content of sesquioxides in the B, as compared with the C horizon, are also features of the true podzol (6). The presence of two B horizons of essentially similar composition, which according to Joffe (6) is evidence of podzolic maturity, has already been discussed in the data for profiles 1 and 3. Base exchange studies of these soils, made by Mitchell and Riecken (10) indicate that while there is little or no unsaturation, the total exchange capacity varies throughout the profile in a manner similar to that of the true podzols (6).

While the Saskatchewan wooded soils studied to date are found under a mixed forest cover, the dominant vegetation consists of poplars (*P. tremeloides* and *balsamifera*). Furthermore, with the exception of the jack-pine sands, the more strongly developed podzolic profiles are also associated with the poplar cover. Where spruce trees predominate the soil is usually of a peaty nature or presents features of a poorly drained podzolic type. It is not known if this present vegetative cover is typical of former conditions. Leahey (8) in his study of Alberta wooded soils found evidence in support of the spruce as the climax type of vegetation, despite the present dominance of the poplar. It is possible that a similar condition obtains in Saskatchewan, but no ecological data are available on this question.

Theoretically the Saskatchewan podzolic soils should have developed under conditions of much greater acidity and higher base unsaturation, and probably in association with a coniferous forest. From this viewpoint these soils must now be undergoing a process of regradation, following the replacement of conifers by the poplar. This theory however does not explain how the poplar became established on the original highly acid soil. As already stated, at the present time the moderately acid podzolic sands are largely covered by jackpine (*Pinus Banksiana*). The black and degraded black sands whose reaction is nearly neutral are dominated by poplar vegetation.

In contrast to the above theoretical considerations there is definite evidence that podzolic profiles have developed under poplar trees in southern Saskatchewan. In the black soils zone and even in the semi-arid dark brown soils there are small clumps of poplar and willow trees, locally known as "bluffs". Where these bluffs surround low moist depressions, they are frequently underlain by podzolic soils with somewhat poorly drained subsoils (13). These soils must have developed under their present cover, as the previous existence of coniferous "bluffs" in a semi-arid grassland region cannot be regarded as even a remote possibility. In addition to the "bluff" podzols the black soil zone contains extensive islands of upland podzolic and degraded black soils under poplar vegetation, situated in areas entirely devoid of coniferous trees. Glassey (2) reported podzolic soils under aspen vegetation in brown, dark brown and chernozem soils of Wyoming.

From the foregoing discussion it is evident that the wooded soils of Saskatchewan do not fit satisfactorily into any of the great soil groups of

the world, as the latter are now defined. Leahey (8) concluded that the presence of calcium carbonate in Alberta wooded soils was not a sufficient reason for excluding them from the podzol group. The data presented in this study justify a similar conclusion regarding the wooded soils of Saskatchewan. They may be regarded as a distinct branch of the podzol family, possessing certain definite characters of their own. This study also suggests that while conditions of strong acidity and high base unsaturation are associated with podzol soils of humid regions, it seems evident that a considerable degree of podzolization may take place under the conditions of slight acidity and relatively low precipitation found in Saskatchewan.

ACKNOWLEDGMENTS

Acknowledgments are due to the following: Dr. F. A. Wyatt, Professor of Soils, University of Alberta, under whose direction the major portion of this study was carried out; Dr. J. L. Doughty, Dominion Soils Laboratory, Swift Current, formerly of the Alberta Soils Department, for helpful suggestions regarding the analytical procedures; Dr. J. Mitchell, Professor of Soils, University of Saskatchewan, for helpful criticism of the manuscript; Mr. A. Tzogoeff, Assistant in Soils, for help in the studies carried out at Saskatchewan; The T. Eaton Company, for financial assistance in the form of a scholarship open to members of the C.S.T.A.

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THE EFFECT OF BORON ON THE RESPIRATORY BEHAVIOUR OF TOMATOES[1]

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[Received for publication July 8, 1938]

Boron has proven to be an important minor element in the nutritional diet of plants. Heretofore no attempt has been made to study its effect on the repiratory metabolism of growing or storage tissues.

Thirty plants of Bonny Best variety were selected for the production of the fruits used in the experiment. These plants were potted in sterile sand after removal from the seed bed on July 7th, 1937. At this time the plants were about 4 inches to 5 inches high.

The feeding of these plants were carried out in the greenhouse by the administration of nutrient solutions. These plants were divided into three series according to boron treatment. Series A received a moderate amount, Series B received a very small amount while C was fed boron to excess.

The stock solutions were made up as follows:

$MgSO_4 . 7H_2O$	—	140 gms.	—	2000 cc. H_2O
KH_2PO_4	—	70 gms.	—	2000 cc. H_2O
$CaCl_2$	—	150 gms.	—	2000 cc. H_2O
KNO_3	—	50 gms.	—	1000 cc. H_2O
NH_4NO_3	—	360 gms.	—	4000 cc. H_2O
$MnSO_4 . 2H_2O$	—	1.23 gms.	—	2000 cc. H_2O
$FeCl_3 . 6H_2O$	—	20 gms.	—	1000 cc. H_2O
H_3BO_3	—	1 gms.	—	1000 cc. H_2O

The method of administering the nutrient solutions was carried out by applying 200 cc. of solution three times a week to each plant. This solution was made up as follows:

Amounts of stock solutions in 2000 cc. of water:

$MgSO_4 . 7H_2O$	—	28 cc. of stock solution
KH_2PO_4	—	31 cc. of stock solution
$CaCl_2$	—	29.6 cc. of stock solution
KNO_3	—	32 cc. of stock solution
NH_4NO_3	—	32.8 cc. of stock solution
$MnSO_4 . 2H_2O$	—	2.1 cc. of stock solution
$FeCl_3 . 6H_2O$	—	10 cc. of stock solution
Series A		
H_3BO_3	—	11.2 cc. of stock solution
Series B		
H_4BO_3	—	0.11 cc. of stock solution
Series C		
H_3BO_3	—	65.0 cc. of stock solution

[1] Contribution No. 515A from the Division of Horticulture, Dominion Experimental Farms System, Ottawa, Ontario.
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Unfortunately the experimental material was moved into an unshaded greenhouse while the fruit on the first truss were still quite green and small. This resulted in a serious set back in growth as well as the development of considerable blossom-end rot. In spite of this fact some healthy-appearing fruit of similar age (50 to 55 days after fruit set) was obtained. One fruit of each series was selected from these and the respiratory behaviour at 55° F. studied.

In order to obtain measurements of CO_2 output the tomatoes were placed in individual gas-tight chambers immersed in a constant temperature bath. A CO_2 free air stream passed over the fruit in the chamber and the CO_2 evolved was collected by absorption in BaOH in Pettenkoffer tubes. Measurements were made by titrating the contents of each tube every 24 hours. The resulting rates expressed in mgms. of CO_2 per Kgm. of fruit are shown in Figure 1.

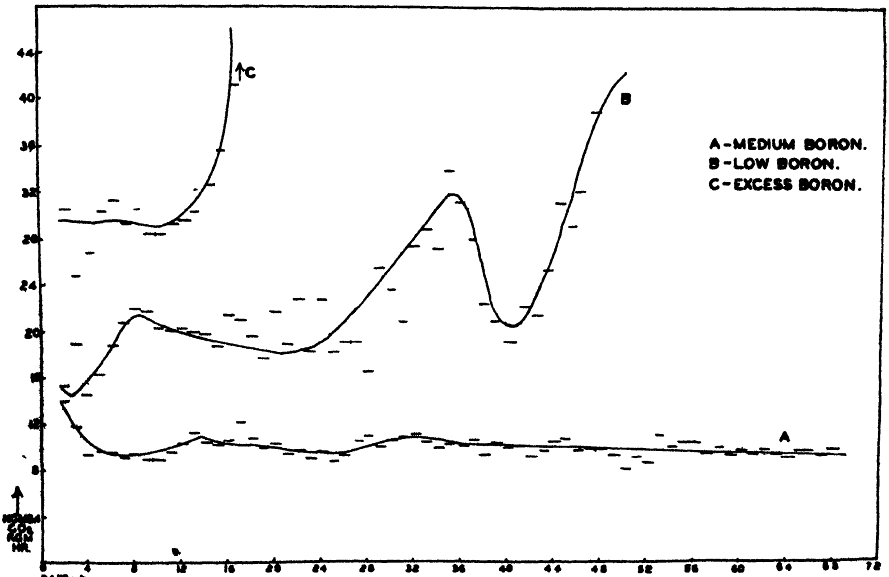

FIG 1 EFFECT OF BORON ON THE RESPIRATION OF TOMATO FRUITS.

The fruits in series A and B were yellow green with A being slightly more advanced than B. The fruit from series C was very slightly orange being considerably more advanced than either A or B.

On account of the accident in growing of the plants and the subsequent lack of material it was at first deemed inadvisable to attempt any theoretical formulations. Nevertheless so great a divergence occurred in the resulting respiratory curves of the tomatoes from the various feeding treatments that a brief survey of their form may be of interest.

Blackman and Parija (1) have shown that apples are of three types as classified by the form of their respiratory drift. The longest keeping types were those of delayed and lower climacteric. Walford (2) found that good keep in tomatoes was associated with a steady respiratory behaviour as determined in his late fall and winter grown tomatoes.

In Figure 1 it will readily be seen that the respiratory curves represented are distinctly different from each other. Curve C, representing a fruit from a plant fed boron to excess, is much higher at the outset. Unfortunately the curve was influenced severely by breakdown at about the sixteenth day. Within this relatively short period there is no indication of the lowest point being as low in CO_2 output as any point in either of the other curves.

Curves A and B commence at approximately the same rate but after several days two distinctly different trends are assumed. Curve B shows extreme fluctuations and evidence of a double senescent hump. This curve assumes an abnormal ascent at about day 44 resulting from the onset of breakdown.

Curve A represents the drift of CO_2 output from a fruit grown on a plant receiving normal amounts of boron. This curve is characterized by low steady rates of carbon dioxide output with the absence of any distinct hump or climacteric. Fruit C was further advanced in colour than B at the outset but remained in good condition for a much longer period.

The effect of boron might be assumed to produce a steadying effect on CO_2 output. If given to excess the rates appear to be steadier than if boron is lacking but assume a higher level. If boron is administered in proper amount a low steady rate is produced which appears to be conducive to better keeping properties.

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